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User Guide

Supplement to DO-160G

RTCA DO-357
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FOREWORD

This document was prepared by Special Committee 135 (SC-135) and was approved by the RTCA Program Management Committee (PMC) on December 16, 2014.

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- analyzing and recommending solutions to the system technical issues that aviation faces as it continues to pursue increased safety, system capacity and efficiency;
- developing consensus on the application of pertinent technology to fulfill user and provider requirements, including development of minimum operational performance standards for electronic systems and equipment that support aviation; and
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Purpose and Applicability

The purpose of this document is to provide users of DO-160G additional background information for the associated test procedures and requirements in DO-160G. This information includes rationale for requirements, guidance in applying the requirements, commentary, possible trouble shooting techniques, and lessons learned from laboratory experience. This User Guide is provided for guidance purposes and does not contain requirements. This information is intended to help users understand the objective and rationale behind the requirements, and to help users develop detailed test procedures based on the general test procedures in this document. It is highly recommended that detailed discussion will take place between the equipment manufacturer and the equipment installer during the development of the test plan.

Note that the User Guide subsections are numbered independently of the subsections in DO-160G.

DO-357 replaces the User Guides previously included in DO-160G.

DO-160G Change 1 has been published to remove all User Guides previously included in DO-160G.

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DO-160G

**Environmental Conditions and Test Procedures
for Airborne Equipment**

User Guide for Section 4

Temperature & Altitude

**Based on
DO-160G Section 4**

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4.UG.0 Temperature and Altitude**4.UG.1 Purpose of the Tests****4.UG.2 General**

1. The measurement of the “ EUT temperature stabilization time” can be performed by one of two methods:
2. A preliminary “engineering test” can be performed using the DO-160G test conditions on the EUT. The maximum value of the “EUT temperature stabilization time” measured should be then included in the determination of temperature cycles and used during the “qualification test”.
3. Instrumented EUT temperature measurement is allowed during the test as long as there is no impact on EUT and test integrity. Use of embedded internal temperature measurement function’ when available’ is also permitted. Prior to start of test user should validate the temperature sensor planned to be used for verification of temperature stabilization.

Note: This test applies to equipment that requires cooling for proper operation during the operating high temperature test, paragraph 4.5.4, has functions whose failure following in-flight loss of cooling would contribute to or cause a failure condition that would prevent the continued safe flight and landing of the airplane, and in which the cooling is externally supplied or powered.

4.UG.3 Equipment Categories**4.UG.4 Definitions of Terms****4.UG.5 Temperature Tests****4.UG.5.1 Ground Survival Low Temperature Test and Short-Time Operating Low Temperature Test**

User guide information applicable to Section 4.5.1, Note 2:

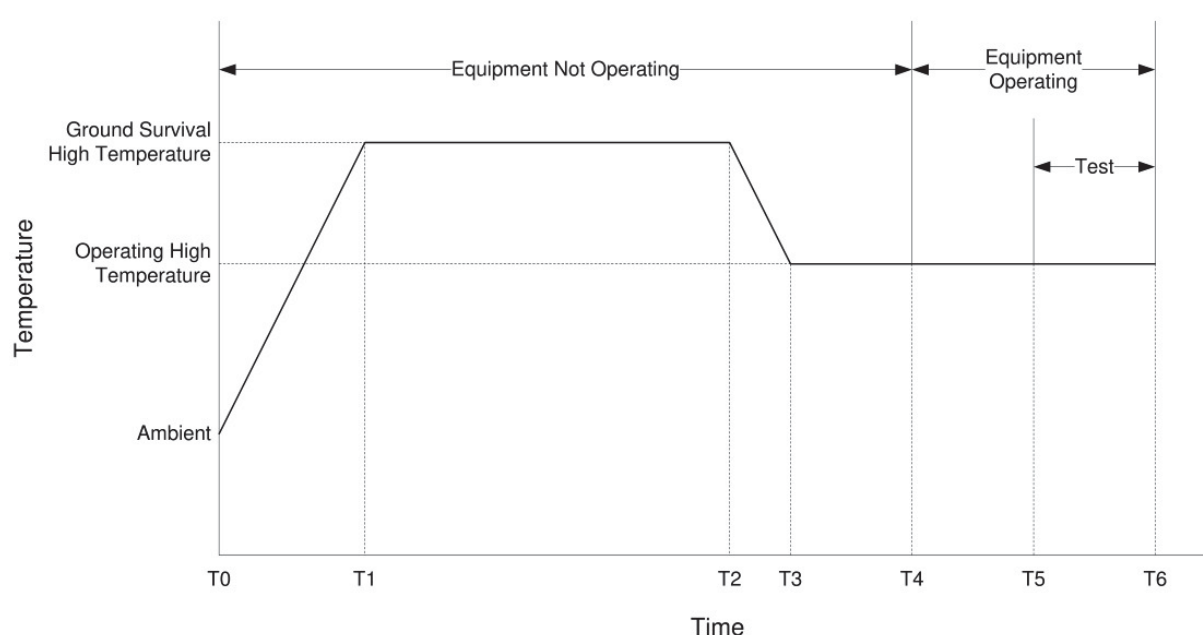
When the Short-Time Operating Low Temperature test is deleted, the intent is that the Ground Survival Low Temperature Test (Section 4.5.1) be combined with the Operating Low Temperature Test (Section 4.5.2); to ensure appropriate cold start conditions are simulated. The combined test is described in Figure 4-UG-1.

4.UG.5.2 Operating Low Temperature Test

4.UG.5.3 Ground Survival High Temperature Test and Short-Time Operating High Temperature Test

User guide information applicable to Section 4.5.3, Note 2:

When the Short-Time Operating High Temperature test is deleted, the intent is that the Ground Survival High Temperature Test (Section 4.5.3) be combined with the Operating High Temperature Test (Section 4.5.4); to ensure appropriate hot start conditions are simulated. The combined test is described in [Figure 4-UG-2](#)



- Note:*
- 1) Temperature change rate from T0 to T1 is not specified.
 - 2) T1 to T2 is time for equipment temperature stabilization time, plus a minimum of three hours.
 - 3) T2 to T3 is at a minimum rate of 2°C/minute.
 - 4) T3 to T4 is 30 +5/-0 minutes or the time for internal stabilization.
 - 5) T4 to T5 is time for equipment temperature to stabilize.

Note: Equipment performance at T4 should be per Note 1 on Paragraph 4.5.3

- 6) T5 to T6 is 2.0 hours, minimum.

Figure 4.UG-2 Combined Ground Survival High Temperature and Operating High Temperature Test

4.UG.5.4 Operating High Temperature Test**4.UG.5.5 In-Flight Loss of Cooling Test**

1. Draft protection to prevent unintended cooling of the UUT through chamber air movement
2. Document the allowance of baffles and or an enclosure. Warning of creating an anti-chamber.

NOTE: To avoid artificial cooling of the EUT, the air in the chamber may be shielded to ensure the air is not being directed onto the EUT. This can be accomplished by use of baffles or vented enclosures inside the temperature chamber. As different chambers use various delivery/return paths, the air delivery system should be reviewed to determine the best method of shielding. If an enclosure is used, it is recommended that a T/C be placed inside the enclosure to monitor the test temperature. The chamber should not be controlled from this thermocouple as the temperature lag between the chamber air, and the enclosure air could put the chamber in thermal runaway.

3. Historically very early versions of DO-160, Section 4 Loss of Cooling, were written for large aircraft installations with centralized avionics cooling systems. The cooling air was delivered by hoses and plenums on the equipment trays. Because equipment manufacturers did not have control of the cooling system, Loss of Cooling tests were required.
4. In the business jet world, OEM's did not want the weight and space of avionics cooling systems and fans were often mounted on the equipment trays. In this case fans were usually powered separately from the avionics equipment and often with 115V/400Hz power.
5. There has also been equipment in use for many years where cooling fans are mounted directly on the equipment and connected to power either through the equipment connector or with converted power in the equipment power supply. The fans mounted in or on the equipment are more likely to be lower voltage and more recently may be quite compact and even board mounted.
6. In Rev. F, the committee added clarification to the application of the Loss of Cooling test and distinguishing were the equipment manufacturer may not have direct control of cooling air or cooling fan power. For equipment with internally powered cooling, we were implying that the fan reliability should, or may, be included in the equipment reliability prediction. Ultimately, the manufacturer is responsible for the equipment reliability and an internally powered fan is assumed to be integral to the equipment.
7. The note in paragraph 4.5.5 makes it clear that the cooling is supposed to be externally supplied or powered, such as dedicated cooling in a cockpit in which the EUT has no direct control over and no way to determine if the external cooling or supply is stopped or shut off.

8. This test does not apply to a EUT which has an internal fan in which the fan power is internally generated or supplied from the EUTs internal power source. The internal fan should be included in the EUT reliability predictions, failure analysis and/or stress analysis and thus its failure should already accounted for in the equipment performance.
9. The definition in Paragraph 4.4:
 “This condition represents the failure of the external or internal system that normally provides dedicated cooling for the equipment. Certain equipment must survive for a limited time in the absence of cooling. Test requirements for this type of equipment shall be specified in the equipment performance specification.”
 The intent of the definition of paragraph 4.4 is:
 “This condition represents the failure of the external system or internal cooling devices, e.g. fans, that normally provide dedicated cooling for the equipment and the cooling supply is externally supplied, powered and/or controlled separate from the EUTs internal power source.
10. DO-160G tests are intended to operate the EUT in its normal operating mode in its operating environment. In this case, the EUT would be operated in a normal operating mode and then a fault is purposely induced to determine its effect and is outside the scope of environmental testing in the normal operating mode. To somehow stop an internal fan is a change to the hardware configuration and may not be consistent with a real failure mode. This additional thermal testing may be part of engineering design evaluations and/or fault or temperature analysis.

4.UG.6 Altitude, Decompression and Overpressure Tests

4.UG.6.1 Altitude Test

There are multiple ways to seal the chamber opening when performing altitude, molded plug, tapered rubber plug, plate compression. Whichever method is implemented, care should be taken to ensure that the seal will not damage any fragile cables. i.e. if a flat plate is used over the chamber opening, do not exceed the bend radius of the cables, do not crush matched impedance cables.

4.UG.6.2 Decompressions Test

It is a good practice to perform the decompression event using a load with a representative volume of the EUT. This will ensure there is not an overshoot condition that could increase the probability of damaging the EUT. Cable harness should be installed during this process to ensure any seal leak is accounted for.

4.UG.6.3 Overpressure Test

1. WARNING: Consult ASME for safety guidance.

2. The overpressure test is specified in absolute pressure. If you are monitoring your environment with a relative pressure device, the specific site pressure needs to be accounted for to perform an accurate test.

DO-160G

**Environmental Conditions and Test Procedures
for Airborne Equipment**

User Guide for Section 5

Temperature Variation

**Based on
DO-160G Section 5**

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5.UG.0 Temperature Variation**5.UG.1 Purpose of the Test****5.UG.2 Temperature Change Rates****5.UG.3 Test Procedure****5.UG.3.1 Test Procedure Categories A, B, and C**

1. When considering combining Temperature Tests with Temperature Variation, the Pros and Cons should be considered. There is a time advantage to combining this testing, but it may present increased risk.
2. If events occur during a combined test, it can be difficult to determine what testing you are able to take credit for. At the worst case, you could have to re-accomplish the entire profile with significant increase in total test time. Also, from a documentation standpoint, it could be difficult to clearly define the test results. If you are testing a product that carries a potential risk of failure, due to redesign, or incorporation of untested components or parts, it may be better to perform temperature and temperature variation testing separately.
3. Below is a Graphical Representation of Combined Temp/Temp variation profiles, with and without Short Time Operating conditions.

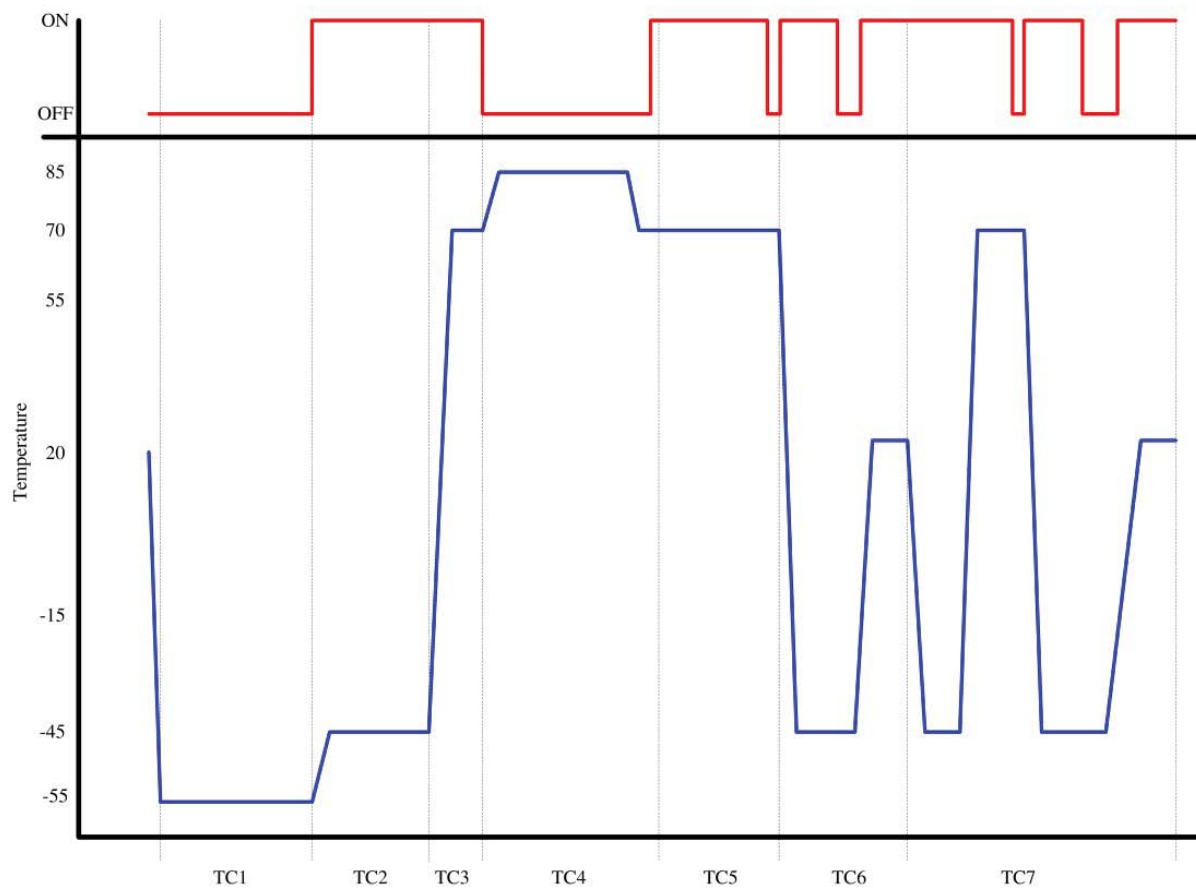


Figure 5.UG-1 - Temp Variation without Short Time Operating conditions

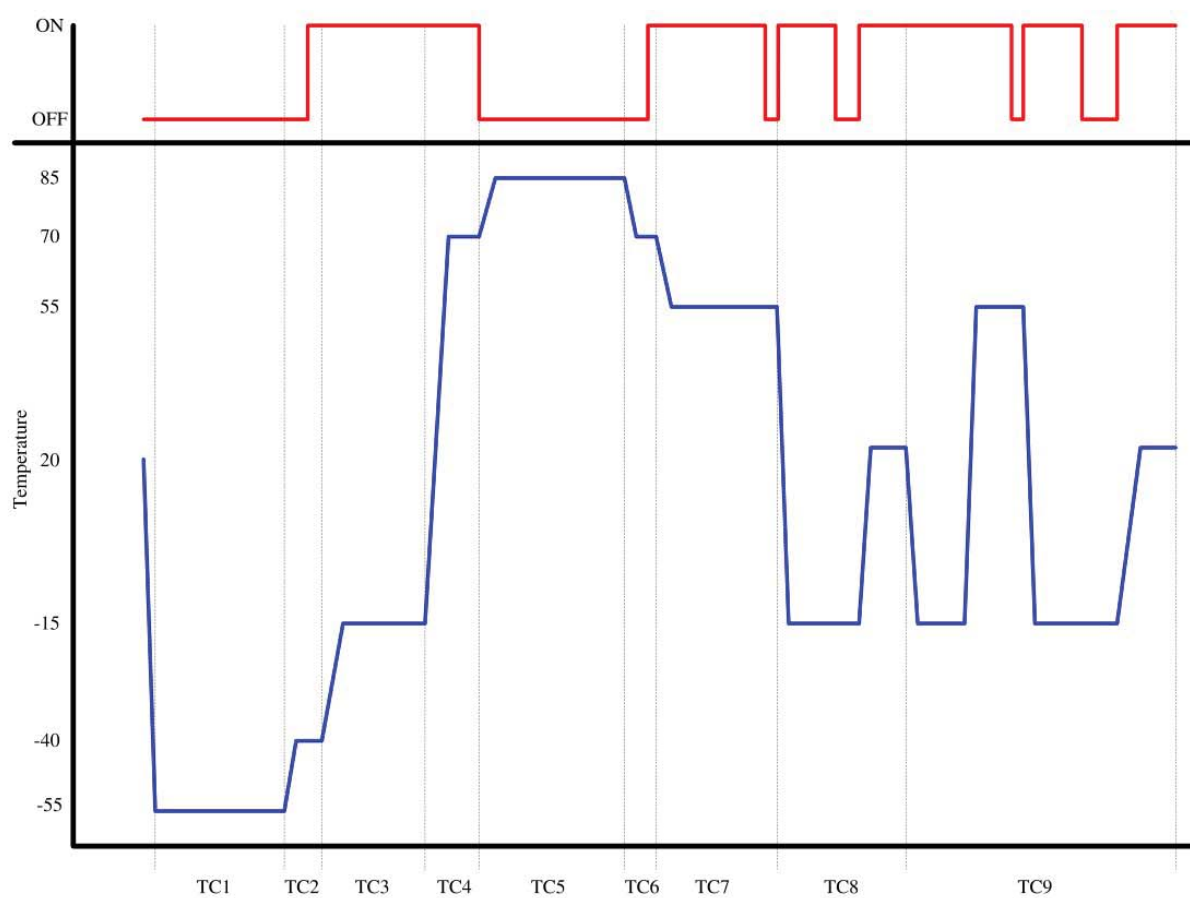


Figure 5.UG-2 - Temp Variation with Short Time Operating conditions

5.UG.3.2 Test Procedure Category S1

5.UG.3.3 Test Procedure Category S2

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DO-160G

**Environmental Conditions and Test Procedures
for Airborne Equipment**

User Guide for Section 7

Operational Shocks and Crash Safety

**Based on
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7.UG.0 Operational Shocks and Crash Safety

7.UG.1 Purpose of the Tests

This section contains some tests that are transient shock pulses or “impulse” tests, and some tests that are static acceleration tests or “sustained” tests. Although both tests are specified with inertial load factors in “g’s”, the two types of tests cannot be directly compared. For example, an impulse test alone should not be used to cover a sustained acceleration requirement. The Section 8 vibration tests are also different types of tests and generally should not be used to demonstrate compliance to Section 7 tests or vice versa without additional analysis.

Another type of shock testing that is not included in DO-160G is repetitive shock typically associated with HALT testing. The repetitive shock testing typically includes repeating shocks with very high frequency content generated by pneumatic hammers. This is also a different kind of test that is not directly comparable to DO-160G shock testing and should not be used to demonstrate compliance to DO-160G shock requirements.

Three different terminal saw-tooth impulse shock durations are listed in Section 7.1, with different peak accelerations for the operational impulse shock and the crash safety impulse shock. Table 7.UG-1 compares the velocity change and displacement change that occurs during the saw-tooth impulse.

Table 7.UG-1: Comparison of velocity and displacement changes during shock

Impulse Shock Test	Duration (ms)	Peak Acceleration (g)	Velocity Change (in/s)	Displacement Change (in)
Standard Operational Impulse Shock	11	6	12.7	0.05
Low Frequency Operational Impulse Shock	20	6	23.2	0.15
Very Low Frequency Operational Impulse Shock	100	6	115.8	3.86
Standard Crash Safety Impulse Shock	11	20	42.5	0.16
Low Frequency Crash Safety Impulse Shock	20	20	77.2	0.51
Very Low Frequency Crash Safety Impulse Shock	100	20	386.1	12.87

The NOTE in Section 7.1 indicates that aircraft acceleration loads may be demonstrated by testing to the “Unknown or Random” orientations for the “sustained” test procedure. Aircraft acceleration loads are typically broken into 2 sets of acceleration loads: limit loads and ultimate loads. Limit loads are typically lower than ultimate loads but have stricter pass/fail criteria where no permanent detrimental deformation is allowed, and equipment may need to demonstrate compliance with applicable performance standards after testing to limit loads. Ultimate loads are typically higher than limit loads but have the same pass/fail criteria as the sustained crash safety loads: bending and distortion are permitted as long as there is no failure of the mounting attachment and the equipment remains in place. Demonstrating compliance to aircraft acceleration loads may require testing to the “Unknown or Random” orientations for the “sustained” test procedure and also using the more conservative pass/fail criteria associated with limit loads so that both limit and ultimate acceleration loads are covered.

The use of the “Unknown or Random” orientation static acceleration load factors in Table 7-1 may cover the aircraft ultimate acceleration loads for many locations on the aircraft, but some installation locations on the aircraft may not be covered. For example, for aircraft type 2, the “Unknown or Random” orientation test is 9g in each of 6 directions, but the up and down ultimate acceleration load factors for equipment mounted on the wingtip may be higher than 9g. This is the reason why Table 7-1 has a “CAUTION” note stating that the test levels may not satisfy the installation requirement in the FARs.

7.UG.2 Equipment Categories

7.UG.3 Operational Shocks

7.UG.3.1 Test Procedure

Section 7.2.1 allows the use of an equivalent shock response spectrum in place of the terminal saw-tooth time history. For reference, the $Q=10$ (5% damping) shock response spectra for the 6 g operational impulse shock is shown in [Figure 7.UG-1](#).

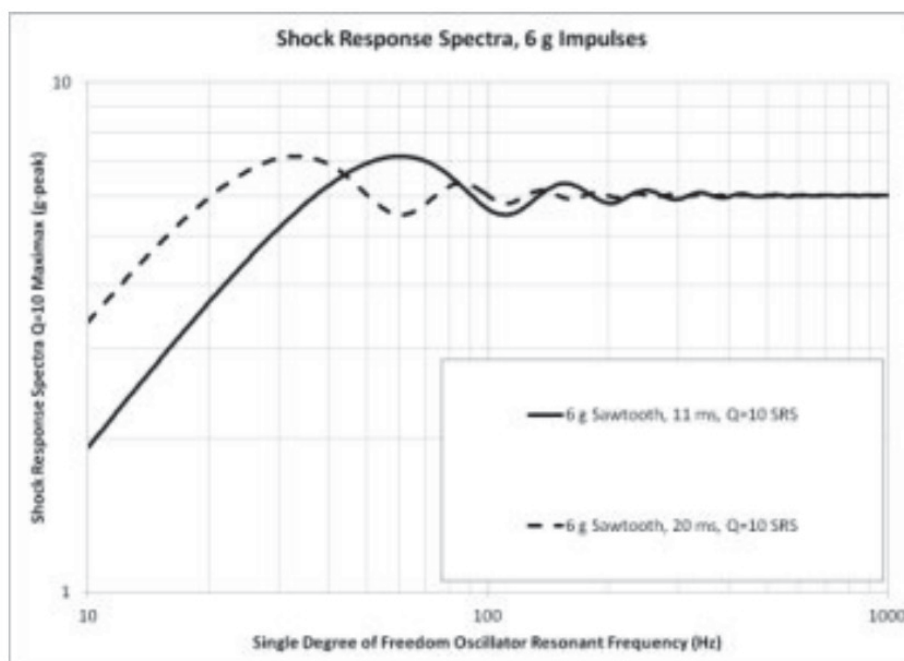


Figure 7.UG-1: Shock Response Spectra for the 6 g shock impulses.

7.UG.3.2 Alternate Test Procedure

7.UG.4 Crash Safety

If the crash safety test is applicable, both the impulse and sustained test procedures shall be performed.

7.UG.4.1 Test Procedure 1 (Impulse)

7.UG.4.2 Alternate Test Procedure (Impulse)

7.UG.4.3 Test Procedure 2 (Sustained)

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DO-160G

**Environmental Conditions and Test
Procedures for Airborne Equipment**

User Guide for Section 8

Vibration

**Based on
DO-160G Section 8**

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8.UG.0 Vibration

8.UG.1 Purpose of the Tests

The vibration tests in section 8.0 are a standardized method used to determine whether installed equipment is able to function as intended during aircraft operation and maintain structural integrity under vibration. The standardization of the test methods reduces the need to define unique vibration requirements for each installation and allow equipment compatibility across aircraft platforms.

While the tests defined in section 8.0 may or may not fully envelope the vibration environment that could be measured for each installation, the tests have been shown to be a useful criterion to identify inadequate equipment designs. Airframe manufacturers, engine manufacturers, and equipment installers may require testing to installation unique vibration environments, which may or may not be more severe than DO-160G.

8.UG.2 Applicability

The aircraft types, as listed in Table 8-1, are the following:

1. Helicopters (Reciprocating & Turbojet Engines).
2. Fixed Wing Turbojet or Turbofan Engines (Subsonic & Supersonic).
3. Fixed Wing Reciprocating & Turboprop Engines, Multi-Engine over 5,700 kg.
4. Fixed Wing Reciprocating & Turboprop Engines, Multi-Engine less than 5,700 kg.
5. Fixed Wing Reciprocating & Turboprop Engines, Single-Engine less than 5,700 kg.
6. Fixed Wing Unducted Turbofan Engines (Propfan).

The test categories are discussed in more detail in section 8.2.1, 8.A.2.1 and their subsections. The three test categories are the following:

- Category S: Standard Vibration.
- Category R, U, or U2: Robust Vibration.
- Category H or Z: High-Level Short Duration Vibration.

The aircraft zones, as listed in Table 8-1, are the following:

1. Fuselage.
2. Instrument Panel, Console & Equipment Rack.
3. Nacelle & Pylon.
4. Engine & Gear Box.
5. Wing & Wheel Well.

6. Landing Gear.
7. Empennage & Fin Tip.

The vibration test curves, as listed in Table 8-1, are the following:

- Standard Random Vibration: B, B2, B3, C, D, and E
- Standard Sinusoidal Vibration: L, M, T, and U
- Standard or Robust Sinusoidal Vibration: W, Y, and Z
- Robust Random Vibration: B & B1, B2 & B12, B3 & B4, C & C1, D & D1, and E & E1
- High-Level Short Duration Sinusoidal Vibration: P and R
- Helicopter Sine-On-Random Vibration: G, H, I, and J
- Helicopter Random Vibration: F & F1

8.UG.3 Vibration Test Category Definitions

The standard and robust test categories are both related to the aircraft vibration environment during normal operating conditions. The robust test is more severe than the standard test. The high-level short duration test is related to sustained engine imbalance conditions and thus is unrelated to the standard and robust test categories.

8.UG.3.1 Standard Vibration Test (Category S)

The standard vibration test demonstrates that equipment will meet its functional performance requirements in the vibration environment experienced during normal operating conditions of the aircraft. It is not intended to represent a service life endurance vibration test.

The use of the word “standard” does not imply that this is the preferred test category. “Standard” is simply the name for this test category.

The standard vibration test is not available for helicopters.

8.UG.3.2 Robust Vibration Test (Categories R, U, U2)

The test requirements of the robust vibration test are of longer duration and sometimes higher level than the standard vibration test. The robust test demonstrates functionality during a performance level vibration test and also demonstrates some degree of physical endurance that can be expected with extended vibration exposure during an endurance level vibration test. However, the robust test may or may not represent a service life test.

8.UG.3.3 High-Level, Short Duration Vibration Test (Categories H, Z)

The High-Level Short Duration (HLSD) vibration test is only applicable to Aircraft Type 2) Fixed Wing Turbojet or Turbofan Engines (Subsonic & Supersonic) and Aircraft Type 6) Fixed Wing Unducted Turbofan Engines (Propfan). See the Aircraft Types listed in DO-160G Table 8-1.

The HLSD vibration test is intended to demonstrate equipment functionality during sustained engine imbalance conditions that result from blade loss or shaft support failure. This test typically is applicable only to equipment with functionality required for continued safe flight and landing after a blade-out event.

FAA Advisory Circular 25-24, “Sustained Engine Imbalance,” dated 8/2/2000, provides additional detail about sustained engine imbalance. More specifically, AC 25-24 defines two imbalance conditions that may affect safe flight: the windmilling condition and a separate high power condition. Reference this Advisory Circular for further details regarding these conditions.

This test alone may or may not be sufficient to demonstrate equipment functionality and/or structural integrity during windmilling and high power conditions since the test amplitudes may not envelope the high power and windmilling environments for the applicable aircraft.

8.UG.4 Test Curve / Test Level Selection

8.UG.4.1 Test Description

8.UG.4.2 Test Curves

Small equipment racks where the shelf is attached to frames, stringers, skin or other fuselage structure should utilize Zone 1: fuselage.

The test curves may not be adequate for an externally mounted item with significant surface area, like a blade antenna.

Equipment that is attached directly to fuselage structure and contained within the wing-to-body fairing is considered part of Zone 1: fuselage.

Zone 2 “Instrument Panel Console and Equipment Rack” also includes interior items attached to the galley interior partitions and cabin main deck floor and is separate from the “fuselage” zone.

See Table 8.A.2.2.2-1 below for the reduction factors for the “Weight Allowance” for a EUT weighing greater than 22.68 kg (50 lbs.). The weight of the test fixture should not be included when evaluating whether a EUT is heavy enough for a weight allowance. The “APSD Factor” in the table would be applied to the g^2/Hz APSD levels for the random tests. The “Sinusoidal Factor” would be applied to the overall g_{rms} levels for the random tests or to the Displacement Double Amplitude (DDA) and g levels for the sinusoidal tests. The factors in the tables are displayed in 5 lb. increments, but the factors can be computed in smaller increments with the following equations:

$$\text{APSD factor:} \quad 10^{(0.1 * [50 - w] / 10)}$$

$$\text{Sinusoidal factor:} \quad 10^{(0.1 * [50 - w] / 20)}$$

Where “w” is the equipment weight in pounds for equipment weighing between 50 lb. (22.68 kg) and 110 lb. (49.90 kg). The reduction factors for heavy equipment should not be used for equipment weighing less than 50 lb. (22.68 kg). For equipment weighing more than 110 lb. (49.90 kg) the maximum reduction of 6 dB should be used. The reduction factors can only be applied to frequencies above 60 Hz.

The weight allowance can be applied to all test curves in Section 8, including the Standard, Robust, and High Level Short Duration categories (categories S, R, U, U2, H, and Z) for a EUT weighing more than 22.68 kg. While a reduction in amplitude is typically appropriate for a heavy weight EUT, for some installations, in particular on helicopters, it may be inappropriate to reduce the test level.

Table 8.UG-1 - Reduction Factors for Heavy Equipment

Reduction Factors for Heavy Equipment Applicable Only Above 60 Hz Applicable to Standard and Robust Test Levels				
Equipment Mass (kg)	Equipment Weight (lb.)	dB Change	APSD Factor	Sinusoidal Factor
22.68 or less	50 or less	0.0	1.00	1.00
24.95	55	-0.5	0.89	0.94
27.22	60	-1.0	0.79	0.89
29.48	65	-1.5	0.71	0.84
31.75	70	-2.0	0.63	0.79
34.02	75	-2.5	0.56	0.75
36.29	80	-3.0	0.50	0.71
38.56	85	-3.5	0.45	0.67
40.82	90	-4.0	0.40	0.63
43.09	95	-4.5	0.35	0.60
45.36	100	-5.0	0.32	0.56
47.63	105	-5.5	0.28	0.53
49.90 or more	110 or more	-6.0	0.25	0.50

8.UG.5 Vibration Test Requirements

- a. The test axes should be defined with respect to the equipment's primary orthogonal axes, without regard to the aircraft installation orientation.

The purpose of a vibration test fixture is to transmit energy from the shaker into the test item without affecting its transmission in any way. In reality, a test fixture affects the frequency, phase and amplitude of the energy it transmits. Although perfect fixtures may not be possible, proper design and preparation early in a test program will help achieve an optimum result.

Vibration fixtures should be as rigid and non-compliant as possible. The ideal fixture will not have modes below 2.5 kHz to ensure the controllability of the test. In some situations test fixtures will have resonances in the test frequency range. This is especially true for large test items. For this reason it is recommended that the fixture-specimen system be experimentally evaluated prior to formal vibration testing. The goal of this pre-test evaluation is to characterize any in-axis or out-of-axis fixture dynamic responses that will affect the actual test. The test plan should allow

modification of vibration test levels and control strategies to mitigate any undesirable fixture effects – both resonance and anti-resonance.

Non-rigid fixtures should not be used because they make controlling vibration input levels extremely difficult or impossible. The difference in stiffness between vibration fixtures and real world installation has been thoroughly documented in the technical literature and is typically referred to as vibration test fixture impedance mismatch.

Equipment that is mounted on external vibration/shock isolators shall be tested with the isolators. If the isolators are not part of the EUT, then they may be changed during the test as they show wear and/or affect the results of the test.

- b. The response accelerometer locations should be carefully considered to ensure that critical responses are recorded. Consider locations that will capture the EUT resonances that contribute most to mechanical fatigue of critical details or resonances that may affect performance. For example, placing an accelerometer on a EUT cover may show multiple resonances of the cover, but the cover resonances may have little influence on mechanical fatigue of critical mechanical components or EUT performance. Response accelerometer locations could affect conformity, especially for locations internal to the EUT. The degree of conformity impact should be considered when selecting EUT accelerometer locations. Response accelerometer locations should be documented.
- c. Control accelerometers should be placed on the fixture as close as possible to the equipment mounting location. A fixture survey is recommended to determine the number of control accelerometers and locations required for the vibration test. The fixture should have a representative mass loading during the fixture survey. Control accelerometer locations should be documented.
- d. [This section is intentionally left blank]
- e. The accuracy of the instrumentation system for measuring sinusoidal acceleration shall be ± 10 percent for acceleration and ± 2 percent for frequency. The values noted here are with respect to the instrumentation accuracy. That is, the accelerometers and other associated instrumentation should be accurate within $\pm 10\%$ for sinusoidal amplitude, and accurate within $\pm 2\%$ for sinusoidal frequency. This instrumentation accuracy requirement is separate from the test control tolerances noted in sections 8.4.1.1 and 8.4.1.2.
- f. CAUTION: While splitting the spectrum into separate frequency bands of 10 Hz to 600 Hz and 600 Hz to 2000 Hz is permissible, it is not recommended due to the complicated dynamics that occur during a random vibration test. The full frequency band is expected to be tested together and the EUT vibration dynamics are extremely difficult, if not impossible, to predict if the band is split. This practice should be avoided if a critical natural frequency is found to be within 600Hz ± 100 Hz.

Other General Guidance

If a condition is present that requires a stoppage of the test, the test may be interrupted and resumed after the condition is resolved.

Guidance for Critical and Resonant Frequencies

The terms “Resonant Frequencies” and “Critical Frequencies” are used and defined in several locations throughout the vibration test procedure. These terms are summarized below along with additional guidance.

Resonant frequencies

Resonant frequencies are defined as response peaks that are greater than twice the input acceleration amplitude.

Resonant frequencies are referenced for Standard Random, Robust Random, and Sine-On-Random test procedures. While the resonant frequencies do not have a direct effect on the test procedure, these frequencies should be clearly identifiable in the APSD plots. These same tests also include a statement regarding recording changes in resonant frequencies in the EQF.

Critical frequencies

Critical frequencies are defined as: (1) resonant frequencies, or (2) frequencies where a change in performance or behavior is noticeable whether or not performance standards are exceeded.

Critical frequencies are referenced for both Standard Sinusoidal and Robust Sinusoidal test procedures. These frequencies are used as special 30 minute dwell frequencies during the Robust Sinusoidal test procedure. These same tests also include a statement regarding recording changes in critical frequencies in the EQF.

Identifying Changes in Critical or Resonant frequencies

The test procedure contains no limits to determine what constitutes a change in Critical or Resonant Frequency. However, the measurement accuracy specifications are $\pm 10\%$ for acceleration/amplitude and $\pm 2\%$ for frequency. Therefore, typically changes within these specified accuracy limits should not be reported as changes.

Generally, resonant frequencies are considered as the frequencies where there is a response peak that is greater than twice the input acceleration amplitude. However, strictly speaking, this could result in a large number of small peaks that still exceed twice the value of the input acceleration amplitude but are all generally part of the same larger resonance. For the purpose of EQF reporting it may not be practical to include literally every peak in the resonant frequency comparison. However, complete detailed plots should be available in the test report for future review.

Resonant frequency changes due to equipment settling

It is useful to monitor EUT resonant frequencies for changes because significant changes in resonant frequencies are sometimes indicative of structural degradation of the EUT or test fixture. However, significant changes in resonant frequency may occur without any associated structural degradation. When testing a recently built EUT and built-up test fixture it is not uncommon to experience fixture or equipment settling. This settling may result in changes in the measured resonant frequencies, even though the settling does not cause structural degradation or performance degradation. Changes in resonant frequency are not part of the pass/fail criteria.

Applying some informal vibration testing prior to formal testing may allow settling to occur such that resonance changes are minimized during the formal test. Reducing the number of nuisance variations due to settling would allow the equipment manufacturer to focus on resonance changes resulting from causes other than settling.

Sinusoidal General Notes

All Sine curves are specified with Acceleration g-level, Displacement Double-Amplitude (DDA), and Frequency. However, only two parameters can be used to set the crossover points. The resulting value of the third parameter will not be exactly equal to the value in the figure. It is recommended to use Acceleration g-level and Displacement Double-Amplitude to set the crossover points. In this case frequency may vary slightly from that specified in the chart.

For example, Figure 8-2 has a breakpoint at 24 Hz, 1.0 g, and 0.036 inches displacement double-amplitude. The crossover frequency is actually closer to 23.31 Hz using a conversion of $1.0 \text{ g} = 386.1 \text{ in/s}^2$. It is acceptable to run the test with the breakpoint at the calculated crossover frequency. Alternately, it is also acceptable to run the test with a constant 1 g input up to 24 Hz, then have a slight discontinuity at 24 Hz to transition up to 0.036 inches DDA.

Random Vibration General Notes

It is generally not accepted to combine random vibration test curves. However, if combining is desired, then it is permissible if the maximum APSD and maximum frequency bandwidths of the curves to be combined are used for the resulting curve. It should also be noted, that the combination of two curves is a more severe test than testing each curve separately on two different EUTs. This would typically be used for a EUT that is qualified for multiple applications or locations.

Acceleration Power Spectral Density (APSD) plots of the control accelerometer(s) should be included in the test report to document that the EUT was tested within tolerances. Since an APSD plot represents just a brief duration, control APSD plots from at least the start and end of a random test should be included in the test report.

The random vibration tests also include a requirement to perform APSD analysis of the response accelerometer(s). The response accelerometer APSD plots include useful data about the EUT response to random vibration excitation and should be included in the test report for reference. The EUT response APSD may be monitored for changes, where significant changes may be indicative of response accelerometer instrumentation problems, EUT settling, or EUT degradation.

Guidelines for EQF reporting requirements

The vibration test procedure includes several Environmental Qualification Form (EQF) reporting requirements. A summary of all such reporting requirements is provided in the table below.

The intent of these requirements was not to include detailed measurement plots in the EQF. Any applicable detailed plots should be available in the test report for future reference.

Generally, references to listing changes in performance were intended to be a reference to listing critical and/or resonant frequency changes. EUT performance requirements are already dictated by the applicable TSO and/or aircraft manufacturer requirements.

Examples for how to sufficiently meet the EQF reporting requirements are provided below. Note that depending on the number of resonances it may not be practical to report literally every peak. See the guidance on critical and resonant frequencies for further guidelines on what differences to report.

In the event that there are no reportable critical and/or resonant frequency changes, then it is acceptable to simply provide a statement similar to the following: “No notable changes to critical and/or resonant frequencies occurred as a result of the applicable vibration testing”.

Table 8.UG-2: Summary of Vibration EQF reporting requirements

<u>Section</u>	<u>Section Description</u>	<u>EQF reporting requirements</u>
8.5.1	Sinusoidal Test Procedure	Any changes in the critical frequencies that occur during the test.
8.5.2c	Random Test Procedure	Any changes in vibration resonance frequencies.
8.6	High-Level Short Duration Vibration Test Procedure	For Category Z, the maximum frequency tested.
8.7.1c	Robust Sinusoidal Test Procedure	Any changes in the critical frequencies that occur during the test. If no change occurs, then note that no changes occurred.
8.7.2d	Robust Random Test Procedure	Any changes in the vibration resonant frequencies.
8.8.1.3 d	Sine-On-Random Test Procedure	Any change in performance
8.8.1.3e	Sine-On-Random Test Procedure	Any changes in vibration resonant frequencies. If no change occurs, then note that no changes occurred.
8.8.3c	Random Test Procedure for Category U2	Any change in the performance or the vibration resonances.

Table 8.UG.3: Example EQF Reporting of Critical and/or Resonant Frequency changes.

Resonant frequency changes are noted below per RTCA DO-160G section 8.5.2.c Random Test Procedure. Standard Vibration – Category S, Curve B. Detailed measurements are available in the test report.

	<u>Initial Sine Sweep before Random Test</u>		<u>Final Sine Sweep after Random Test</u>	
<u>Axis</u>	<u>Frequency (Hz)</u>	<u>Acceleration (g)</u>	<u>Frequency (Hz)</u>	<u>Acceleration (g)</u>
X	161	1.3	152	1.1
Y	464	1.4	469	1.5
Y	1609	1.7	1609	1.1
Z	111	6.9	108	8.5
Z	159	1.5	159	1.3
Z	288	1.5	289	1.7
Z	319	1.4	308	1.7
Z	431	1.2	429	1.3
Z	1063	1.8	1057	2.0

8.UG.6 Vibration Test Level Requirements

8.UG.6.1 Control Level Tolerance Requirements

8.UG.6.1.1 Sinusoidal Control Input

The +/- 10% tolerance on the sinusoidal control input may be applied to a bandpass-filtered control signal, rather than a broadband control signal. A bandpass-filtered signal will be representative of the amplitude at the input frequency and filters out content at other frequencies.

8.UG.6.1.2 Random Control Input

For items of large mass that can be difficult to control, a typical practice is to allow a small percentage of the cumulative bandwidth to be out of tolerance. The out of tolerance bandwidth should be limited to a maximum of 5 percent of the test frequency range.

If out of axis input motions are measured, it is recommended that these out of axis inputs be limited to 100% of the in axis input.

8.UG.6.2 Measurement of Acceleration Power Spectral Density**8.UG.6.2.1 Analog Analyzer Requirements****8.UG.6.2.2 Digital Analyzer Requirements**

The requirement stated in DO-160G Section 8.4.2.2 is that analysis and control systems shall use a bandwidth-time (BT) product greater than or equal to 50. The bandwidth “B” is the frequency resolution of the APSD, and the time “T” is the full duration of time used for averaging the APSD. The bandwidth-time product is related to the number of ensemble averages or degrees of freedom (DOF) used to calculate the APSD. A bandwidth-time product greater than or equal to 50 corresponds to a minimum of 50 linear averages or 100 DOF. As an example, with a bandwidth B=5 Hz, the minimum time used for APSD calculations would be $50/5 = 10$ seconds.

8.UG.7 Standard Vibration Test Procedure-Fixed Wing Aircraft**8.UG.7.1 Sinusoidal Test Procedure****8.UG.7.2 Random Test Procedure****8.UG.8 High-Level, Short Duration Vibration Test Procedure****8.UG.9 Robust Vibration Test Procedure-Fixed-Wing Aircraft****8.UG.9.1 Sinusoidal Test Procedure****8.UG.9.2 Random Test Procedure**

The existence of EUT performance monitoring during testing at the endurance test levels is intended to provide a means to eliminate the need to perform a second performance level vibration test after completion of the endurance level vibration test. If EUT performance monitoring does not occur during testing at the endurance test levels, then repeat the performance level test as directed.

8.UG.10 Vibration Test for Helicopters**8.UG.10.1 Sine-on-Random Test Procedure – Known Helicopter Frequencies****8.UG.10.1.1 Test Frequencies**

The intent of this section is to help to define the significant disturbance frequencies. The helicopter manufacturer may define the significant disturbance frequencies. The list of test frequencies from DO-160G may not cover all the significant disturbance frequencies. Some helicopter manufacturers have considered FG to be the Tail Drive shaft one rev frequency.

8.UG.10.1.2 Sine and Random Test Levels**8.UG.10.1.3 Procedure****8.UG.10.2 Sine-on-Random Test Procedure for Category U– Unknown Helicopter Frequencies**

Category U may be applied to Zone 1a (fuselage) and Zone 2 (instrument panel, console, & equipment rack). Category U should not be applied to zone 1b (tail boom).

8.UG.10.3 Random Test Procedure for Category U2 – Unknown Helicopter Frequencies

The purpose of Category U2 is to provide an alternative procedure for labs that don't have sine-on-random test capability.

Category U2 is applicable to Zone 1a, Zone 1b, and Zone 2. Note that Category U2 is applicable to Zone 1b (tail boom) and Category U is not applicable to Zone 1b.

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DO-160G

**Environmental Conditions and Test Procedures
for Airborne Equipment**

User Guide for Section 9

Explosive Atmosphere

**Based on
DO-160G Section 9**

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9.UG.0 Explosive Atmosphere**9.UG.1 Purpose of the Test**

This section of DO-160G is intended to provide test procedures and test levels that can be used to test equipment for explosive atmosphere. It is the responsibility of the installer to make sure the test results satisfy the certification requirements of the proposed installation. This User's Guide does not contain requirements; it is intended to provide background information and considerations that improve the likelihood of successful test results.

9.UG.2 Explosion Proof**9.UG.3 Equipment Categories****9.UG.3.1 Category A Equipment**

For Cat A and Cat H equipment, claiming for hermetically sealed design allow reducing significantly the amount of test required for these Category. Because hermetically sealed is not a standard definition, especially in the frame of section 9, when claiming for such design, the equipment supplier should make sure before going for test that all persons, from Aircraft supplier to Authority, which are involved in the process, will agree that the design proposed meet the intent of "hermetically sealed" as considered for section 9. This may include, for Cat A in particular, some consideration of failure mode associated with this design.

Hermetically sealed can be considered as an EUT which cannot be internally penetrated by flammable test fluids, vapors or gases at maximum pressure and temperature described in the product specification.

9.UG.3.2 Category E Equipment**9.UG.3.3 Category H Equipment****9.UG.4 General Test Requirements****9.UG.4.1 General****9.UG.4.2 Test Specimen****9.UG.4.3 Fuel****9.UG.4.4 Fuel Mixture**

9.UG.5 Equipment Design and Installation Information**Aircraft Zone Definitions and Equipment Requirements**

Equipment should be installed in aircraft zones depending on:

- 1.) Their ability to prevent vapor explosion during their normal functioning
- 2.) The probability that exists in considered zone
- 3.) Abnormal functioning in failure mode. Definition of Zones is provided below.

Aircraft Zone I

Aircraft Zone I is an aircraft area in which uncovered flammable fluids or vapors exist, or can exist, either continuously or intermittently (e.g., in fuel tanks or within fuel or hydraulic systems). Equipment installed in such environment shall not be able to ignite the surrounding atmosphere in their normal or double failure conditions of operation.

Aircraft Zone II

Aircraft Zone II is a designated fire zone or an aircraft area where a single fault will result in spillage or leakage to create flammable mixtures. Equipment installed in such Environment shall not be able to ignite the surrounding atmosphere in their normal or faulty possible operation modes. Only equipment single failure should be considered.

Aircraft Zone III

Aircraft Zone III is a designated fire zone or an aircraft area where a single fault will not result in spillage or leakage to create flammable mixtures. Equipment installed in such Environment shall not be able to ignite the surrounding atmosphere in their normal operation modes.

Aircraft Zone IV

Aircraft Zone IV is a designated fire zone or an aircraft area where a double fault will not result in spillage or leakage to create flammable mixtures. No requirement applies to equipment located in such zone.

9.UG.6 Test Procedures**9.UG.6.1 Containment Test****Preparation for Test**

The EUT dimensions may not physically allow the introduction of an igniter and a tube/pipe to allow circulating the explosive atmosphere through the EUT. In addition, the internal volume of the EUT may not allow combustion to occur.

In these cases, marking the EUT Qualification Test Form with Category X may be an acceptable alternative. This alternative should include discussions between the equipment manufacturer and the equipment installer. The rationale for this determination should be documented.

9.UG.6.2 Non Ignition Test**Performance of Test**

Step 2: In order to avoid incomplete vaporization of mixture, a recommended way to check development of a homogenous mixture is to check the explosiveness of a sample of the mixture as for step 4.

This verifies the mixture before and after the test in step 3.

Note that it is not required to do the explosive check of the mixture in the whole test volume but only on a sample of this atmosphere.

9.UG.6.3 Components of Surface Temperature Test**Failure Criteria**

If faulty modes are to be tested, the equipment should be turned on and operated in its possible faulty modes until thermal stabilization of the equipment has been attained. The temperatures attained at the suspected components or surfaces should be recorded continuously from the initial powering of the equipment to its stabilization. If a temperature in excess of 204°C is attained at any time during the period, the test should be terminated.

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DO-160G

**Environmental Conditions and Test
Procedures for Airborne Equipment**

User Guide for Section 10

Waterproofness

**Based on
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10.UG.0 Waterproofness**10.UG.1 Purpose of the Test****10.UG.2 Equipment Categories****10.UG.3 Test Procedures****10.UG.3.1 Condensing Water Proof Test****10.UG.3.2 Drip Proof Test**

It is recommended to clean and maintain the drip proof test dispenser in order to ensure calibration requirements of paragraph 10.3.1 are met.

Experience has shown that a temperature differential between the test item and the rainwater can affect the results of a rain test. A temperature difference of about 10°C higher than the rain temperature at the beginning of each exposure period, to subsequently produce a negative pressure inside the test item, will provide a more reliable verification of its waterproofness.

Temperature stabilization requirements can be referenced in Section 2, paragraph 2.1.

10.UG.3.3 Spray Proof Test

If multiple shower heads are used simultaneously, each individual showerhead emits a volume of water greater than 450 liters per hour.

10.UG.3.4 Continuous Stream Proof Test

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DO-160G

**Environmental Conditions and Test Procedures
for Airborne Equipment**

User Guide for Section 11

Fluids Susceptibility

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11.UG.0 Fluids Susceptibility**11.UG.1 Purpose of the Test****11.UG.2 Precautions****11.UG.3 Equipment Categories****11.UG.4 Test Procedures****11.UG.4.1 Spray Test****Fluid Equivalencies**

With regards to deicing fluids, the AEA (Association of European Airlines) states that Types I, II, III, and IV refer to the latest version of applicable ISO or SAE fluid types, i.e. SAE Type I and AEA Type I are the same fluid. In the case of identical fluids, either fluid may be used, but both temperatures should be tested.

Fluid Concentrations

The intent is to apply the fluid manufacturer's recommended concentration, similar to actual application on aircraft. It is good practice to document the fluid concentration utilized during testing and record in the test log or report.

11.UG.4.2 Immersion Test**11.UG.5 Use of Material Specimens**

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DO-160G

**Environmental Conditions and Test Procedures
for Airborne Equipment**

User Guide for Section 15

Magnetic Effect

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15.UG.0 Magnetic Effect

15.UG.1 Purpose of the Test

This test determines the magnetic effect of the equipment. This test ensures that the equipment can operate properly without causing interference which may affect the nearby equipment, determining equipment compliance with the applicable equipment performance standard, or assisting the installer in choosing the proper location of the equipment in the aircraft. The test consists of two primary steps:

1. Verification of a uniform ambient magnetic field.
2. Testing.

The distances provided allow the unit to be placed in specific locations within the aircraft. Many times the category is given before the time of test and then tested to ensure that the unit can be placed at a specific distance required for a specific installation.

15.UG.2 Test Description

The test may be performed using a magnetic sensor, such as an ordinary compass. However, with today's improvement of electronic sensors, a calibrated magnetometer with at least two axes of measurement parallel to the earth's surface may also be used.

Some essential formulae and definitions are given below:

- B - Magnetic Flux Density
 - SI Units: Tesla (T); CGS units: Gauss (G)
 - $1 \text{ T} = 1 \text{ Wb/meter}^2 = 10^{-4} \text{ G}$
- H = Magnetic Field Strength
- SI Units: Amperes/meter (A/m); CGS units: Oersted(Oe)
- $1 \text{ A/m} = 4\pi \times 10^{-3} \text{ Oersted (Oe)} \sim 1 \text{ Oe}/79.58$
- μ_0 - Permeability of free space
 - SI System: $4\pi \times 10^{-7} \text{ Hy/meter}$; CGS system: 1 Oe/G
- μ_r – Relative permeability, assumed to be 1 for air (free space).
- HCAFS = Horizontal Component of the Earth's Magnetic Field (B_0).
 - Natural field present in the plane parallel to the Earth's surface
- D_c – Equivalent deflection angle to be used in determining equipment category.
 - $$D_c = \frac{14.4 \text{ A/m}}{\text{HCAFS}}$$
- $1 \text{ Hy} = 1 \text{ (T*meter}^2\text{)}/(\text{Ampere*Turns}) = 1 \text{ Wb}/(\text{Ampere*Turns})$

Starting with equation (1)

$$(1) \mathbf{B} = \mu_0 \mu_r \times \mathbf{H}$$

Rearranging Equation (1) and solving for H (magnetic field strength in A/m),

$$(2) \mathbf{H} = \frac{\mathbf{B}}{\mu_0 \mu_r}$$

Equation (3) presents the derivation of the 14.4 A/m. Choosing $B_0 = 18100$ nT from the National Oceanic and Atmospheric Administration's (NOAA's) magnetic model as a round number that is reasonably close to the value around 40° N, 100° W and substituting this value for B,

$$(3) H_0 = \frac{B_0}{\mu_0} = \frac{(18100 \text{ nT})}{(4\pi \times 10^{-7} \text{ henries/m})} = 14.4 \text{ A/m}$$

It has been somewhat arbitrarily determined that equipment shall not be installed such that it affects the magnetic sensitivity of adjacent equipment by an amount exceeding the equivalent of one degree of magnetic deflection.

For an EUT to deflect a compass needle by one degree from magnetic north, the EUT must induce a field at the compass location which is perpendicular to the Earth's natural field, and has intensity H_1 equal to $H_0 \tan(1^\circ)$, or $H_1 = 0.01745 H_0 = 0.2514$ A/m. The test procedure is designed to determine the distance at which the EUT induces a magnetic field strength of 0.2514 A/m, using a magnetic compass as the measuring device, and a nominal observation of one degree of deflection.

However, if the local natural field (HCAFS) varies from 14.4 A/m, the deflection caused by an induced field of 0.2514 A/m will vary in proportion to the ratio H_0/HCAFS . Therefore, in order to precisely determine transverse field strength of 0.2514 A/m using a magnetic compass, one must observe a deflection angle D_c , according to equation 4:

$$(4) D_c = \frac{14.4 \text{ A/m}}{\text{HCAFS}}$$

Therefore, when $\text{HCAFS} = 14.4 \text{ A/m} \pm 10\%$, D_c is equal to 1° as shown in equation (4). The basis for this is somewhat arbitrary, but does provide a value that normalizes measurements to the middle of the United States.

An EUT may deflect the magnetic sensor by D_c at a certain distance. It can be seen by Equation (4) the allowable deflection angle from magnetic north decreases as the HCAFS increases. Thus it is essential to record the HCAFS at the location of test.

15.UG.3 Test Procedure

The EUT is typically powered in the mode with the highest current draw. This has been shown to produce the highest magnetic field in most cases. The cable harness should be electromagnetically representative of the aircraft harness, and should follow the guidance of Section 20. The power lines may need to be lengthened during this test to minimize the

possibility of fields from the power supply corrupting the results. The orientation of the cabling along the East-West line is to maximize the effect of any magnetic materials or EUT fields that the compass may detect.

The test can be performed by either of the following two methods:

- Measure a uniform ambient field in a specified volume and move the sensor to the unit.
- Measure the ambient field at a specified location and move the unit under test to the sensor.

Test procedure in 15.3.1 requests HCAFS to be measured if unknown, which is generally the case due to the possible influence of installation in or around the laboratory facilities. Measuring the HCAFS is typically done using a magnetometer or Gauss meter. Another method uses a Helmholtz coil. Whatever the method used, it should be documented in the test procedure. It is recommended that the test location be reviewed for sources of high magnetic field generating items so that the ambient HCAFS is well behaved.

The overall test method can be summarized as follows:

1. Measure the HCAFS at location of test with a calibrated magnetometer, or as defined above using a Helmholtz coil.
2. If the HCAFS is 14.4 A/m (or 18 μ T) $\pm 10\%$, the allowable Dc is 1°. If the HCAFS is outside of this tolerance, calculate Dc using Equation (4) in Section 15.2.
3. Along the East/West direction, move the EUT toward the magnetometer or the compass towards the EUT, depending on the test method being performed. Record the distance at which the magnetometer reading has deflected by angle D_c . This distance determines the category of the EUT.

Measuring and Calculating the Local HCAFS

Equipment Required

- a. DC regulated power supply capable of constant current operation, approx. 1 amp capability
- b. Calibrated ammeter
- c. Helmholtz Coil
- d. Compass

Helmholtz Coil

NOTE: The Helmholtz coil must of the “standard” configuration where the center to center distance between the coils along the axes of the coils is equal to the radius of the coils. Each coil must have the same number of turns. The coils are to be connected in a series aiding configuration.

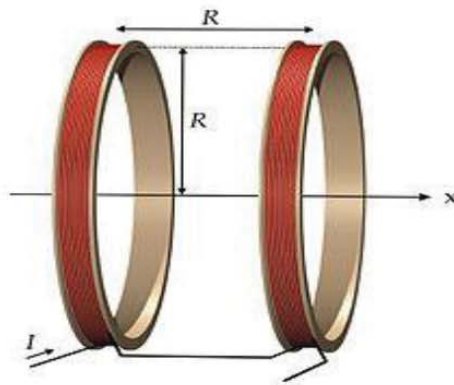


Figure 15.UG-1 - Helmholtz coils

If it is desired to construct Helmholtz coils, there must be no ferrous materials used in the coil frame or supports. Brass or plastic is suggested for all parts and fasteners. Care should be taken to ensure that the wire used is capable of withstanding the anticipated maximum coil currents without damaging the wires or coil forms.

A search of the internet will provide ample guidance for the construction of Helmholtz coils.

HCAFS Calculation Procedure

NOTE: Remove all ferro-magnetic items from test area before beginning procedure

1. Turn the power supply and ammeter off.
2. Connect the Helmholtz Coil in series with the ammeter and DC constant current power supply.
3. Set the power supply to constant current mode.
4. Align the Helmholtz coils so that the axes of the coils are aligned approximately North/South.
5. Place a compass as close as practical in the center of the Helmholtz coil working volume.
6. Rotate the compass until it reads approximately 0 degrees.
7. Set the power supply to minimum current. Turn on the ammeter.
8. Turn on the power supply.
9. Adjust the power supply current to produce a 1 gauss field within the Helmholtz coil.
10. Rotate the compass until it reads 0 degrees.
 - a. If the compass swings to 180 degrees, reverse the power supply leads.
11. Turn off the power supply.
12. Without disturbing the compass, rotate the Helmholtz coil until the compass reads 0 degrees.
13. The goal is to see no movement of the compass needle or dial when the power supply is switched from On to Off.
 - a. This ensures that the magnetic field produced by the Helmholtz coils are aligned to the earth's magnetic field.

14. Repeat as needed to satisfy the conditions in Step 13.
15. Turn off the power supply.
16. Without moving the compass, rotate the Helmholtz Coils until the compass reads 90 degrees or 270 degrees.
17. Set the power supply for minimum current.
18. Turn on the power supply and the ammeter.
19. Adjust the current until the compass needle or dial deflects 45° from its initial position.
20. Record the current from the ammeter, and use this value to calculate the magnetic field in A/m using the following formula:

$$H \approx 0.715 \frac{NI}{R}$$

where:

H = the magnetic field in amperes / meter

N = number of turns

I = current in amperes

R = coil radius in meters

21. Using the value from the previous formula, divide by the DO-160G Section 15 magnetic flux density constant to calculate the deflection angle as shown in the equation below.

$$\text{Deflection Angle} = \frac{14.4 \frac{A}{m}}{H}$$

Note: If the EUT is quite large, several compass locations should be considered on a side of the EUT to maximize the deflection. All sides should be evaluated for the maximum deflection. There are instances when it is not practical due to the mounting of the EUT or the known placement in the aircraft. All measurement locations should be described in the test procedure.

Factors that can improve accuracy on test.

- Normally a magnetic compass is used to measure a uniform field. During the test of Category Y and Z the magnetic compass can be located very near the EUT where the field is not uniform. An evaluation of the effect of distance from EUT vs size of compass would need to be taken into consideration.
- The resolution of compass would need to be correctly selected for the intended category in order to perform good measurements.
- For Y category, the distance (measured from the center of the compass) will be limited to the size of the compass. This implies that the compass would touch the EUT. The size of the compass may determine the overall distance from the EUT. Therefore, a small size of compass would be recommended in order to perform such a measurement.

- Some magnetic fields are non-stationary (relay coils that switch during time, for example). A mechanical compass averages a rapidly varying field due to the inertia of the needle. Different magnetic field measurement devices (eg, magnetometer or electronic compasses) respond differently.
- When using a magnetometer, physical identification of the north south pivot line will result in increased accuracy.

DO-160G

**Environmental Conditions and Test Procedures
for Airborne Equipment**

User Guide for Section 16

Power Input

**Based on
DO-160G Section 16**

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16.UG.0 Introduction

Power supply input addressed in this section concerns only lines connected directly to the aircraft bus bar. Any Power supply provided as an output of equipment not part of the A/C PWS network shall be assessed specifically.

During the equipment test, it may be desirable to perform the test on multiple EUTs of a single or multiple systems at once. This could be beneficial to evaluate the response of highly integrated systems. It could also save a great deal of time if system level testing for other DO-160G sections is to be performed (e.g. if a system bundle must be built to support qualification, then the same bundle could be used for multiple EUT testing within section 16). Many of the test conditions defined in section 16 could then be applied to the system simultaneously, and provided proper monitoring is used, credit could then be taken for all EUTs in the system.

The disadvantage would be the requirement of a larger power supply or generator. In some cases or some tests, additional monitoring equipment may be required to monitor multiple EUT's at once.

The usage of a system level section 16 testing should be established on a case-by-case basis. There are several tests which may be impractical or inappropriate to perform at a system level.

There could be interaction between EUTs. It may not be covered or allowed by certification plans and conformities. The intention of this system level test is to find gross problems.

This alternate method is only applicable for test environments that are strictly a voltage requirement test. This does not apply to tests which contain current requirements (see [Table 16.UG-1](#) for test applicability). Care should be taken that the waveforms are properly produced.

DO-160G does not forbid or state that this is an acceptable way of running the tests with multiple EUT's in parallel. It is recommended to consult with the air-framer to confirm the required test method.

See [Table 16.UG.1](#) "Multiple Equipment Level Testing Table" which recommends power quality tests which may be performed with multiple EUTs in parallel on the power bus.

16.UG.1 Voltage distortion

The following are the reasons for the Voltage Distortion Test.

- The quantity of nonlinear loads and percent of nonlinear loads on Aircraft Power Buses has been increasing over time. The result of the increase of the quantity of Non-Linear loads is the voltage distortion of the power buses have been increasing (getting worse).

- The equipment manufacturers must be able to operate with distorted voltage inputs because it is very likely to happen on aircraft power buses.
- Aircraft tend to have multiple instances of loads. There are times where many loads are in standby mode where power factors may not be well controlled.

The equipment must operate properly with a 10% voltage distortion input voltage. The purpose of this test is to verify proper operation of the EMI filter and the power supply. Properly designed EMI filters will not dissipate excessive power in the damping components during this test. It is acceptable to use either an external circuit or a programmable power supply to produce the distorted input voltage. It is acceptable to use higher distortion than specified for this test.

Programmable power supplies are typically used for high power levels because of the challenge in designing the external rectifier and filter. The harmonics that produce the distorted waveforms are not specified in DO-160G. There are many ways to produce 10% distortion. Different Airframe manufactures may have different requirements for generating the distorted waveform. The method used should be documented in the test procedure and the test report.

16.UG.2 Momentary Power Interruptions (dc)

For single and multiple EUTs the voltage envelope should be measured at the EUT input. The distance should be as close as practical to the EUT, with 7 inches (0.18 m) or less is recommended.

It is required that the voltage envelopes defined in Table 16-3 and Table 16-7 be applied to the unit. In some situations, a EUT may have energy storage devices on the power inputs which will hold the voltage up, and thereby distort the waveform by holding up the voltage above the envelope defined. It is not the intention of the test to allow this to happen. The power supply should be able to sink current during the power interruption.

The voltage waveform should be achieved at the EUT during this test. The following are possible implementations to achieve the momentary power interruption waveform:

- 1) The source power supply should have adequate load capability to avoid power supply current limit.
- 2) Consider using a Programmable power supply that can sink current.
- 3) Consider adding parallel loads across the DC input during the test to help discharge the EUT capacitors.

DO-160G only requires that the EUT does not require a manual reset after a power interruption. The equipment specification, not DO-160G, defines how the EUT is to perform during and after a power interruption.

The double interruption test is intended to verify that the EUT will recover after the interruption without manual reset.

16.UG.3 Abnormal Surge Voltage (AC and DC)

The intention of the abnormal surge voltage test is to apply the voltage waveform defined in figures 16-5 and 16-6. There is no current limit specified, and this is intentional. This test is intended to validate that the EUT can withstand abnormal voltage levels in the event of electrical network failure. In both of these situations, the power available could be extremely high, and a typical aircraft generator or ground power unit could supply enough current to meet the defined waveform.

If the generator being used is unable to supply enough current to create the applicable voltage waveform, a larger generator is required or a lower category (whatever is achievable) must be claimed.

In some cases, depending on the EUT, the waveform may be distorted upon application. Inductive ringing due to the EUT load would be an example. In such an event, it is desirable to verify the source power supply output either into an open circuit, or across a resistive load, to verify the source of the distortion. If the source power supply does not cause the ringing in these cases, and the waveform applied meets the desired characteristics (e.g., 80 V is achieved in 1 ms in the DC case) then the test is considered acceptable. It is intention of this test that the rise and fall times should be met even if ringing and/or distortion occur.

A fuse or circuit breaker may be inserted in series with the test generator during the testing; however the required voltage and rise time must be generated at the EUT input terminals. If the fuse blows or breaker opens during application of the test waveform the EUT has not met the requirement.

16.UG.4 Current Harmonics

When using harmonic analysis equipment, the Hanning, Hamming, Blackman-Harris windowing are preferred over Rectangular windowing to avoid distorting the amplitudes of the harmonics.

16.UG.5 Current Distortion:

It is suggested to use the nominal source voltage for the I_1 input current spec limit for this test. If the nominal voltage is not used, justification should be provided.

16.UG.6 DC Current Content in Steady-State Operation (All ac Equipment)

Measuring the dc current drawn by ac equipment is intended to be done with a digital multimeter (DMM) set to measure current. If there is significant current modulation (Designation L) or harmonics (Designation H) there could be problems measuring the dc current with a DMM.

There are line powered DMMs with “slow” (i.e. lower bandwidth) settings that can be used to reject current modulation.

It is suggested to verify the test equipment setup through a test load before performing the test.

It is suggested that the test method be included in qualification test procedure.

16.UG.7 Inrush Current

The intention of this section is to measure inrush current of the EUT. DO-160G limits are to control transients and are generally concerned with inrush at normal operating conditions. The secondary goal is to avoid circuit breaker trips. This may require a digital oscilloscope which can capture at a high sampling rate for at least two seconds.

16.UG.8 Current Modulation test in steady state operation

The goal of this test is to measure the lower frequency modulation of equipment input current (current contents above power network fundamental frequency are characterized in the current harmonics test). Current modulation may modulate the power network voltage due to generator regulation bandwidth and/or generator and power distribution impedance. A possible way to perform this test is to digitize the input current over 500 ms periods, and then extract the rms current value cycle-by-cycle. From those extracted cycle-by-cycle rms values, peak, valley and average values can be calculated leading to the defined current modulation.

$$\frac{I_{\text{PEAK}} - I_{\text{VALLEY}}}{I_{\text{RMS}}} \leq 0.28 \quad \text{FOR POWER LEVELS LESS THAN 1kVA}$$

$$\frac{I_{\text{PEAK}} - I_{\text{VALLEY}}}{I_{\text{RMS}}} \leq 0.14 \quad \text{FOR POWER LEVELS GREATER THAN OR EQUAL 1kVA}$$

I_{PEAK} = Maximum Modulated Current

I_{VALLEY} = Minimum Modulated current

I_{RMS} =rms value of the equipment maximum steady state current

Current Modulation LTSpice EXAMPLE:

{LT Spice is a registered trademark of Linear Technology Corporation. This program was used to generate the waveforms shown in [Figure 16.UG-1](#). The waveforms are not actual data.}

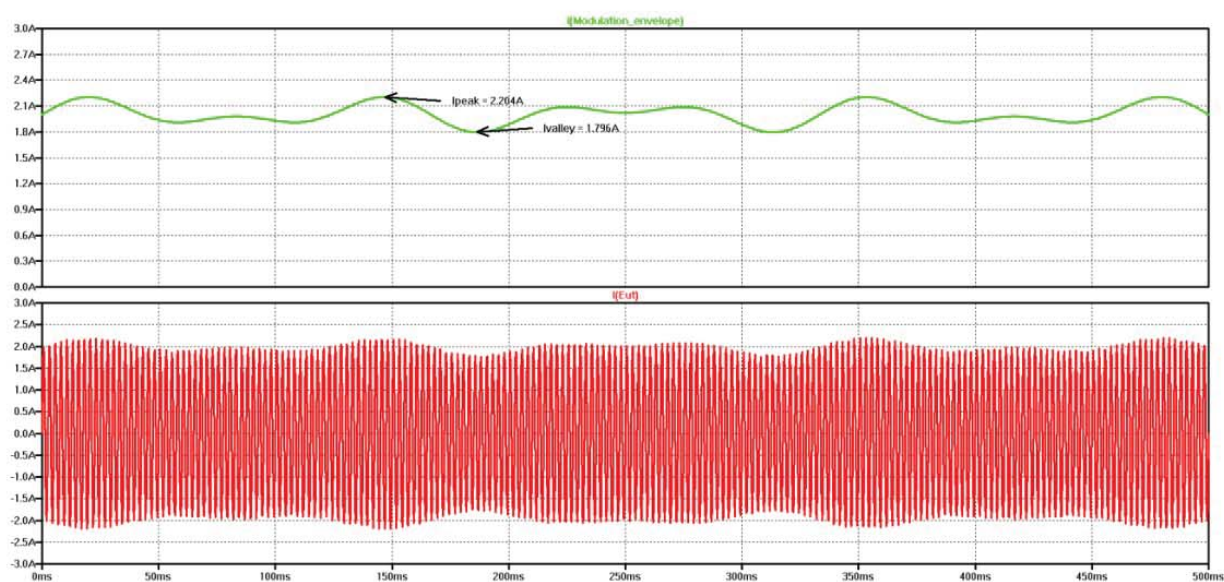
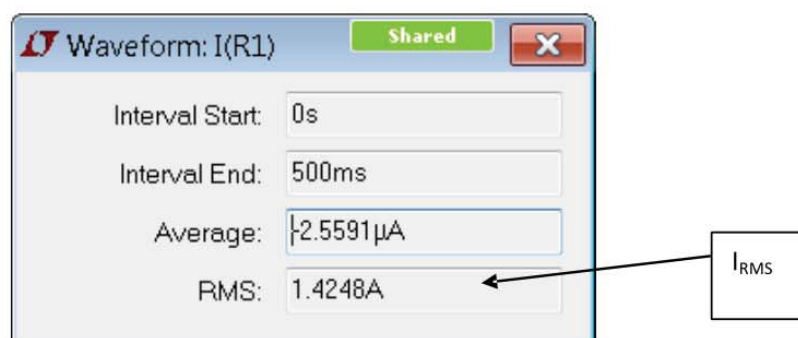


Figure 16.UG-1: Top - Extracted Modulated Current, Bottom - Equipment Steady State Current



Equation:

$$\frac{I_{\text{PEAK}} - I_{\text{VALLEY}}}{I_{\text{RMS}}} \leq 0.28 \quad \text{FOR POWER LEVELS LESS THAN 1kVA}$$

$$\frac{I_{\text{PEAK}} - I_{\text{VALLEY}}}{I_{\text{RMS}}} \leq 0.14 \quad \text{FOR POWER LEVELS GREATER THAN OR EQUAL 1kVA}$$

Example Continued:

$$\frac{2.204\text{A} - 1.796\text{A}}{1.4248\text{A}} = 0.286$$

The result is greater than 0.28

Therefore, this example shows a FAILURE.

16.UG.9 Power Factor

It is suggested that the test report include Displacement Power Factor leading or lagging phase angle information.

The user is reminded that "lead" or "lag" applies only to the phase displacement of the fundamental current waveform with respect to the applied voltage waveform, as expressed by the "Displacement Power Factor" or DPF. In the absence of current harmonics, the Power Factor (PF) is equal to DPF. In the presence of harmonic currents, $PF = DPF/DF$, where DF ("Distortion Factor") is defined as the ratio of total rms current to the rms value of the fundamental current component.

Table 16.UG-1 - Multiple Equipment Level Testing Table

Test Paragraph	Paragraph Number	Multiple Equipment Testing Recommend (Yes / No)	Comment
Voltage Distortion	<u>16.5.1.8</u>	No	<i>Interaction between EUTs can cause problems.</i>
Engine Starting Under Voltage Operation (DC)	<u>16.6.1.5</u>	Yes	
Momentary Power Interruption / Momentary Under voltage Operation	<u>16.6.1.3</u> <u>16.6.2.3</u>	Yes	Must achieve the voltage across all EUTs.
Normal / Abnormal Surges (DC)	<u>16.6.1.4</u> <u>16.6.2.4</u>	Yes	<i>Each individual EUT must be appropriately monitored to determine compliance with the applicable equipment performance standards.</i>
Voltage Steady State (DC)	<u>16.6.2.1</u>	Yes	Multiple Equipment level testing may be accomplished by monitoring bus voltage and all applicable EUT's. Each individual EUT must be appropriately monitored to determine compliance with the applicable equipment performance standards.
Low Voltage Conditions (DC Category B Equipment Only)	<u>16.6.2.2</u>	Yes	Multiple Equipment level testing may be accomplished by monitoring bus voltage and all applicable EUT's. Each individual EUT must be appropriately monitored to determine compliance with the applicable equipment performance standards.
Normal / Abnormal Surges (AC)	<u>16.5.1.5.1</u> <u>16.5.2.3.1</u>	Yes	Each individual EUT must be appropriately monitored to determine compliance with the applicable equipment performance

			standards.
Exposed Voltage Decay Time	<u>16.6.1.6</u>	No	Testing multiple EUTs in parallel may provide inaccurate results.
Current Harmonics	<u>16.7.1</u>	No	Each individual EUT must be monitored individually during the testing
Regenerative Energy	<u>16.7.4</u>	No	Testing multiple EUTs in parallel may provide inaccurate results.
Inrush Current	<u>16.7.5</u>	No	Testing multiple EUTs in parallel may provide inaccurate results.
Current Modulation	<u>16.7.6</u>	No	Testing multiple EUTs in parallel may provide inaccurate results..
Power Factor	<u>16.7.8</u>	No	Testing multiple EUTs in parallel may provide inaccurate results.

DO-160G

**Environmental Conditions and Test Procedures
for Airborne Equipment**

User Guide for Section 17

Voltage Spike

**Based on
DO-160G Section 17**

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17.UG.0 Voltage Spike

17.UG.1 Purpose of the Test

This section of DO-160G is intended to provide test procedures and test levels that can be used to test equipment for Voltage spikes at the equipment power leads. It is the responsibility of the installer to make sure that the test results satisfy the certification requirements of the proposed installation. This User Guide does not contain requirements; it is intended to provide background information and considerations that improve the likelihood of meaningful test results.

17.UG.2 Equipment Categories

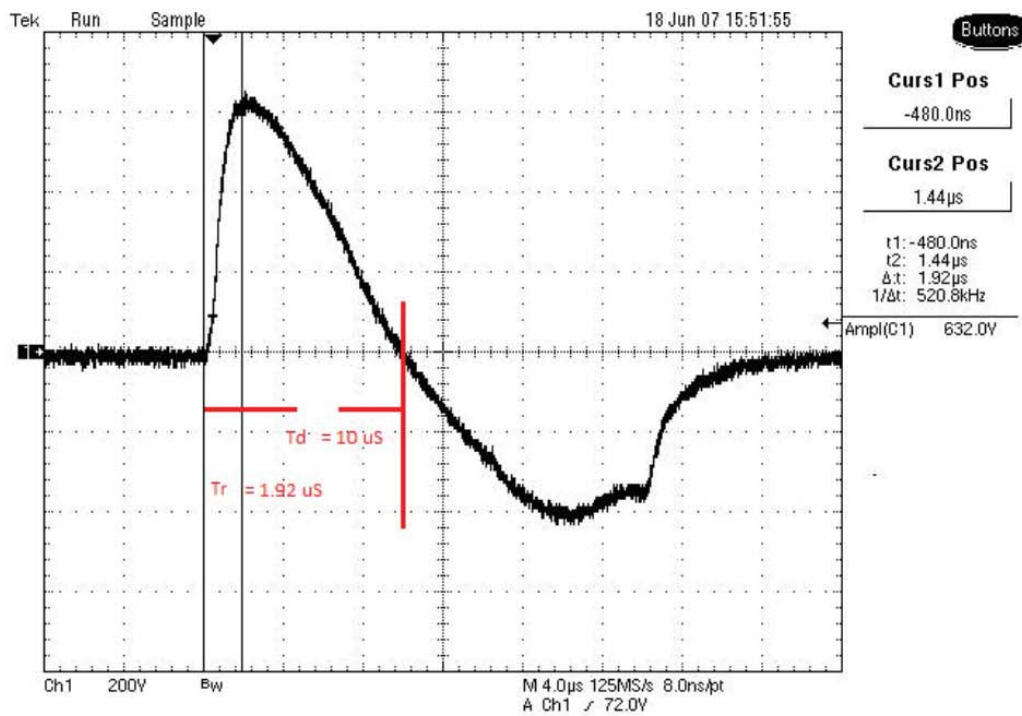
Section 17 includes two test categories, Category A (600 volts peak) where a high degree of protection is required; and Category B (2 x line voltage or 200 volts peak, whichever is less) where a lower standard of protection is acceptable.

17.UG.3 Test Setup and Apparatus

Any method of generating the spike may be used if the waveform complies with [Figure 17.UG-1](#). Common elements used to perform this testing include a transient generator, a coupling transformer, a ten μF capacitor, an oscilloscope and a low inductance 50 ohms load. Most of the generators typically used to perform this test have an internal source impedance of 5 ohms, so in these cases a matching transformer or other devices are needed to meet the 50 ohms source impedance required by [Figure 17.UG-1](#). Where EUT operating currents are extremely high, special or custom coupling transformers may be required. In general commercially available transformers for Section 17 uses are available with EUT current carrying capabilities up to 100 amps.

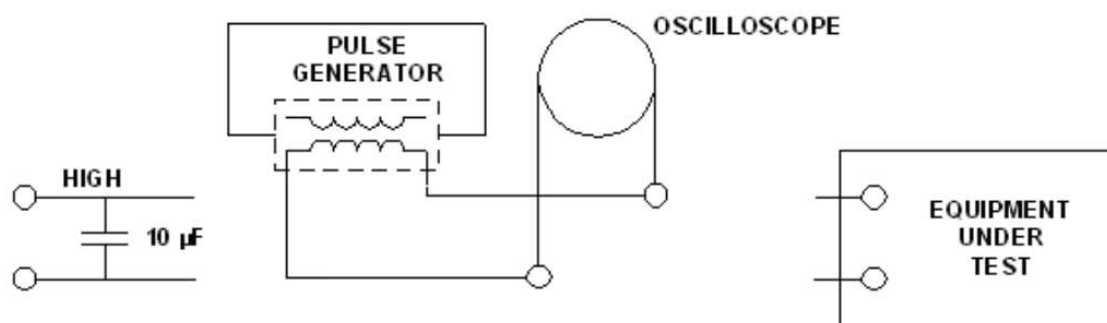
17.UG.4 Test Procedure

Prior to testing the EUT, the voltage spike waveform and salient parameters are verified by performing a calibration. The calibration is accomplished for both positive and negative polarities of the transient spike waveform. The requirements call for a rise time to applicable peak of 2 μSec or less, a minimum spike duration of 10 μSec duration (from the beginning of spike to zero crossing) and a verification that the source impedance of the generator is 50 ohms. The trailing portion of the waveform (after the zero crossing of the spike) is not controlled by the test requirements. A typical waveform recorded during test calibration is included in [Figure 17.UG-1](#). During application of the voltage spike to the EUT, there is no requirement that the applied wave shape be the same or similar to the calibration waveform (the applied waveform parameters will be determined by the electrical characteristics of the line under test). The transients are applied to the EUT as described in Section 17.4 of the procedure and shown in [Figure 17.UG-2](#).

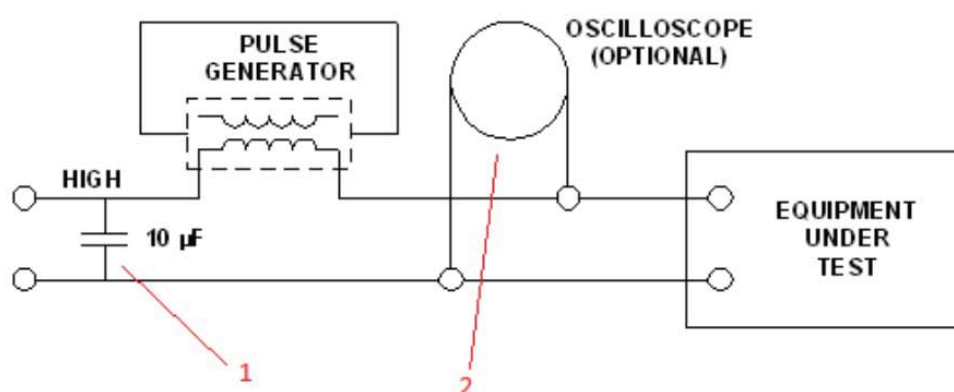


The measured calibration waveform shown above is typical. Note the trailing edge of the waveform (after zero crossing of the spike) only resembles [Figure 17-1](#). The waveform requirement is accomplished if the pulse rise time is less than or equal to 2 μ Sec and the total pulse duration is at least 10 μ Sec.

Figure 17.UG-1: Typical Measured Voltage Spike Calibration



The calibration set up shown above is for determining the open circuit spike voltage. A 50 ohm resistor is placed across the output of the coupling transformer and the transient spike is then re-measured to verify the source impedance (i.e. voltage amplitude $\frac{1}{2}$ test level $\pm 10\%$).



The calibration is then followed by application of the spike to the EUT is shown above. The following notes are added here for clarity.

Note 1: Since the applied transient is coupled in series, Kirchhoff's voltage law states that the voltage appearing across the transient generator output terminals must drop around the circuit loop formed by the EUT input and the power source impedance. The transient voltage level specified in the limit is measured across the EUT input because part of the induced voltage can be expected to drop across the source impedance. A 10 µF capacitor is added across the power source to reduce the voltage drop across the power source impedance.

Note 2: While the procedure does not require monitoring of the applied waveform during testing, it is very useful to do so; i.e. any change in the waveform over the set of applications can be an indication of undesired changes to the EUT or set up.

Figure 17.UG.2: Voltage Spike Test Setup Details

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DO-160G

**Environmental Conditions and Test Procedures
for Airborne Equipment**

User Guide for Section 18

Audio Frequency Conducted Susceptibility – Power Inputs

**Based on
DO-160G Section 18**

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18.UG.0 Audio Frequency Conducted Susceptibility Power Inputs

18.UG.1 Purpose of the Test

This section of DO-160G is intended to provide test procedures and test levels that can be used to test equipment for audio frequency conducted susceptibility of power input lines. It is the responsibility of the installer to make sure that the test results satisfy the certification requirements of the proposed installation. This user's guide does not contain requirements; it is intended to provide background information and considerations that improve the likelihood of meaningful test results.

18.UG.2 Equipment Categories and Frequency Classes

For AC equipment, Categories R(CF), R(NF), and R(WF) correspond to Categories A(CF), A(NF), and A(WF) in section 16, respectively.

For DC equipment, Categories R, B, and Z correspond to Categories A, B, and Z in section 16, respectively.

18.UG.3 Equipment Categories

18.UG.4 Test Procedures

-Many of today's higher powered audio frequency amplifiers have very low output impedances (on the order of 0.1 ohm). In order to use amplifiers such as these, a series resistor may be placed between the output of the amplifier and the primary winding of the transformer, sized such that the sum of the resistor value and the amplifier output impedance is 0.6 ohm $\pm 50\%$ impedance on the transformer's secondary winding. (For example, a transformer and resistor combined impedance of 1.2 to 3.4 ohms will result in a 0.6 ohm $\pm 50\%$ at the secondary of a 2:1 audio isolation transformer). Note that the 0.6 ohm source impedance is based on legacy equipment used during the early versions of this test.

-In some installations, the power return is not connected locally to the ground plane, but is isolated from ground. In these cases, it may become necessary to isolate the voltage measurement device from ground in order to properly measure the injected signal. Several methods exist to isolate the voltage measurement device, including the use of differential probe amplifiers and isolation transformers in-line with the power input to the measurement device. The benefit of using a differential probe amplifier is that it does not present a potential shock hazard, as does using an isolation transformer on the power input to the measurement device.

The intent of the test is to produce the voltage on the EUT power lines. If the voltage is reached during the test, the current does not need to be measured, but this may result in an overtest if the current limit is exceeded. The 36 A_{p-p} limit was provided to protect the EUT from damage if there are resonant effects of the power line filter.

18. UG.5 DC Input Power Leads

- a. Figure 18-2 from DO-160G is intended to measure from the return line to the chassis.

18. UG.6 AC Input Power Leads

- a. Phase shifting networks (PSN) should generally be avoided when performing this test. PSNs introduce extra elements in the measurement path, and can introduce errors in measurement resulting in either overtest or undertest if not tuned properly.
- b. The figures in section 18 show all measurements being taken across the EUT **INPUT TERMINALS**. While the capacitor across the power supply serves to provide a low impedance for the AFCS test signal, so that most of the AFCS signal delivered to the system is applied to the EUT, there is still an impedance associated with the supply and capacitor. Kirchoff's voltage law states that the voltage input across the secondary winding of the isolation transformer will be equal to the sum of the voltages across the EUT and the capacitor/power supply combination. This results in the voltage across the EUT being lower than the voltage across the secondary winding of the isolation transformer. For this reason, measurements should not be taken across either the secondary winding of the transformer, or "voltage measurement windings", if present, on the transformer.

18. UG.7 Frequency Scan Rates

The test steps per decade and dwell times were determined as the optimum values based on "best" designs and "worst" designs. In the case of a "worst" design, more steps may be needed to find all of the failure points. In the case of "best" designs, the longer dwell times are needed to induce overheating in damping elements of the input power circuitry.

18.UG.8 General Remarks

- a. The 36 A_{p-p} current limit is based on the 100 W power limit and 0.6 ohm source impedance present in DO-160E. Both originated from test equipment historically used during performance of this test. 36 A_{p-p} is derived from 100 W as follows:

- b.

$$P = (I_{rms})^2 R$$

$$I_{p-p} = (I_{rms}) (2\sqrt{2})$$

$$100 \text{ W, dissipated in } 0.6 \text{ ohms: } \sqrt{\frac{100 \text{ W}}{0.6 \text{ ohm}}} = 12.91 \text{ A}_{rms} = 36.52 \text{ A}_{p-p}$$

- c. The 0.6 ohm source impedance is based on legacy equipment used during the early versions of this test. The tube amplifiers used when these specifications were standardized had roughly 2 to 2.5 ohm output impedance, which resulted in 0.5 to 0.6 ohm impedance on the secondary of the isolation transformer.

-
- d. When a transformer is used to couple the audio frequency energy into the power lead, it must be capable of performing adequately when the ac or dc load current drawn by the equipment under test flows through its secondary winding.
 - e. On ac lines, phase shifting networks should not be used, due to the potential for inaccurate measurements when using these devices.
 - f. Caution must be exercised so that reflected voltages developed by input power current do not damage the audio power source generation system.
 - g. The dc offset of the audio generator feeding the transformer can cause the audio generator and/or transformer to overheat and fail. A capacitor paralleled with a 1 ohm resistor inserted between the audio generator and transformer will prevent this problem. Both the capacitor and resistor must be rated for the current passing through it. The capacitor must have low enough impedance to allow the required test levels to be achieved.
 - h. The capacitors shunt current away from the power source and create a closed loop with the EUT.

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DO-160G

**Environmental Conditions and Test Procedures
for Airborne Equipment**

User Guide for Section 20

Radio Frequency Susceptibility (Radiated and Conducted)

**Based on
DO-160G Section 20**

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20.UG.0 Radio Frequency Susceptibility (Radiated and Conducted)

20.UG.1 Purpose of the Test

The purpose and scope of this User Guide is to provide additional information and clarification on the test procedures for section 20. However it is still highly recommended that detailed discussion takes place between the aircraft and the equipment manufacturer, if known, before running the test.

The purpose of testing to Section 20 is to ensure that equipment will continue to operate within its performance specification when the equipment and its wiring are exposed to levels of RF current and RF fields of defined levels. Two test procedures are used. First, the injection of RF currents by means of specially designed injection probes into the interconnecting bulk cables and/or individual power lines of the equipment. Second, an electric field illumination of the equipment and its wiring by means of an antenna in an anechoic chamber or in a reverberation chamber.

The tests are designed to simulate the effects of high power onboard or external RF transmitters, such as radar or communications transmitters.

20.UG.2 Equipment Categories

The equipment categories define the RF test levels and establish the minimum RF immunity level for the Equipment Under Test (EUT). The category to be chosen may be defined in the equipment's Minimum Operational Performance Specification (MOPS) or an Airframe Manufacturer's Performance or Procurement Specification. The user should also consult RTCA DO-307 "Aircraft Design and Certification for Portable Electronic Device (PED) Tolerance" and EUROCAE ED-130 "Guidance for the Use of Portable Electronic Devices Onboard Aircraft" to determine appropriate test levels.

Section 20 categories can be chosen either directly due to the requirement stated in the HIRF regulations or according to the envelope of aircraft manufacturer specification for the aircraft onto which the equipment is intended to be installed. For a given aircraft, the required Categories may vary according to frequency range, i.e., Cat Y may be used for conducted test and radiated test in the frequency range of 100 MHz to 400 MHz, Cat W for the frequency range of 400 MHz to 1 GHz and Cat L for the frequency range of 1 GHz to 18 GHz.

The adequacy of the choice of any category used to test level A equipment or system will have to be justified for certification in view of the actual Aircraft installation. It is strongly recommended to discuss such levels with the Aircraft designer, if known, before running the test. In the case where such specification is not available, the following paragraph gives some guidance on how to decide which Category should be used.

For conducted susceptibility categories:

Cat Y/O: These level should be appropriate when level A equipment under consideration is located in very severe electromagnetic environments, which are defined as areas external to metallic or conductive composite structures, and other open areas where no shielding is provided. Cat Y will cover a broader range of installations but may not even be sufficient for compliance to Rotorcraft severe environment (Env III) in the case of very exposed wires that are routed far from any metallic structure, therefore behaving as efficient receiving antenna.

- Cat W: This level should be appropriate when level A equipment under consideration is located in severe electromagnetic environments, which are defined as areas outside the fuselage such as wings, fairings, wheel wells, pylons, control surfaces, etc. where minimal shielding is provided and where the coupling is nevertheless minimized by routing the wire bundles close to the conductive structure. Cat W will generally not be sufficient for compliance to Rotorcraft severe environment (Env III) for wire routed external to the fuselage without shielding. This definition is not appropriate for equipment installations more appropriately described by the definition of Cat Y Location.
- Cat M: This level should be appropriate when level equipment under consideration is contained entirely within a moderate electromagnetic environment, which is defined as the fuselage of a metallic aircraft or composite aircraft demonstrating equivalent shielding effectiveness. Examples of such an environment are avionics bays not enclosed by bulkheads, cockpit areas, and locations with relatively large apertures, i.e. doors without EMI gaskets, windows, access panels, etc. Current carrying conductors in this environment such as hydraulic tubing, control cables, cable bundles, metal cable trays, etc. are not necessarily electrically grounded at bulkheads. Cat M may not be sufficient for compliance to Certification environment (Env I) for long and most exposed wires routed internal to the fuselage of Rotorcraft and large aircraft. This definition is not appropriate for equipment installations more appropriately described by the definitions of Cat W and Cat Y Locations.
- Cat R: This category is primarily used for bench testing of level B equipment as required by the HIRF rules. It could nevertheless be appropriate to comply with level A equipment HIRF requirement when the equipment under consideration is contained entirely within a well-protected environment, which is defined as the fuselage of a metallic aircraft or composite aircraft demonstrating adequate shielding effectiveness. Cable bundles in this environment passing through bulkheads should have shields terminated at the bulkhead connector. Cable bundles should be installed close to the ground plane and take advantage of other inherent shielding characteristics provided by metallic structures. Current carrying conductors such as hydraulic tubing, cables, metal cable trays, etc., should be electrically grounded at all bulkheads. This definition is not appropriate for equipment installations more appropriately described by the definition of Cat W, and Y locations.
- Cat T: This category is primarily used for bench testing of level C equipment as required by the HIRF rules. It could nevertheless be appropriate to comply with level A equipment HIRF requirement when the equipment under consideration, all interfaces to/from equipment, and the cable bundles are contained entirely within a well-protected environment, which is defined as an electromagnetically enclosed area that has been designed with specific electromagnetic faradizations rules. This definition is not appropriate for equipment installations more appropriately described by the definitions of levels Cat W and Y locations.

Cat S: This category should not be used. It could be considered acceptable only when the equipment can be disturbed by external HIRF sources or onboard avionic spurious radiation without generating any significant consequences for the aircraft operation.

The following conducted and radiated susceptibility categories are often used in testing of level A systems. Most radiated categories directly relate to the environments defined in HIRF regulations. (Reference SAE ARP 5583A / EUROCAE ED-107 for definition of Level A systems.)

Categories "B, D, F, G, L, M, Y, W and O" are intended to provide test levels which allow covering the various HIRF external field environments as defined in the HIRF certification advisory documentation. The category selection for the conducted susceptibility test is given in terms of expected aircraft type, dimensions, and the appropriate HIRF environments as shown in [Table 20.UG-1](#). The category selection for the radiated susceptibility test is given in terms of the expected level of aircraft attenuation at the equipment installation location and the appropriate HIRF environment as shown in [Table 20.UG-2](#).

In particular these categories provide adequate certification evidence for systems performing a Level A Display function.

For conducted susceptibility testing the primary limit (test level) is in terms of induced current on the wiring bundle under test with the secondary limit (test limit) being in terms of the forward power to the injection probe. This allows for direct comparison with induced cable bundle current measurements on aircraft. The test procedure was changed in DO-160F, where Categories R, S, T, W, and Y previously used the calibration forward power as the primary limit and current as the secondary limit.

The reader must be familiar with the HIRF requirements before selecting test levels from this section.

For equipment that are part of systems performing functions defined as Level A other than Display, it is recommended to also consider the test set-up requirements of the HIRF User Guide (SAE ARP 5583A / EUROCAE ED-107). This would allow a useful equipment level test which may reduce the need for system or aircraft immunity testing providing the measured aircraft environment is less than the test levels chosen.

The three HIRF environments in the HIRF rules are

- Rotorcraft Severe now renamed Environment III
- Certification now renamed Environment I
- Normal now renamed Environment II

With these 3 different environments, 4 different aircraft categories are considered for establishing generic coupling curves.

The following tables should be used as guidelines for the selection of categories for the conducted and radiated test and to define applicable test levels. The old and new environment terminology is given e.g. HIRF Environment I was formerly known as the Certification Environment.

For the conducted susceptibility test of level A displays the category selection is given in terms of expected aircraft type and related environment as shown in [Table 20.UG-1](#). The

aircraft type is broken down into rotorcraft and three types of fixed wing aircraft broken down in terms of their fuselage length. The category applicable to "all types" is defined as this may be of use to equipment suppliers who make a product that covers a wide range of types. The category "all types" is a worst-case composite of all the individual aircraft types. Categories given between parentheses are also suitable to cover the case although they were not defined for that purpose. The levels for the categories in the parentheses meet or exceed the levels for the categories that are outside of the parentheses.

Table 20.UG-1: Category Definition for the Conducted Susceptibility Test in Terms of Aircraft Type and HIRF Environment

Aircraft	Rotorcraft Severe Environment (HIRF Environment III)	Certification Environment (HIRF Environment I)	Normal Environment (HIRF Environment II)
Rotorcrafts	Y	O (Y)	O (Y)
AC<25m	Not applicable	M (W)	M (W)
AC <50m, >25m	Not applicable	M (W)	M (W)
AC>50m	Not applicable	O (Y)	O (Y)
All types	Not applicable	O (Y)	O (Y)

The radiated susceptibility categories are defined in terms of the various HIRF environments and the expected level of attenuation at the location of the equipment on the aircraft (Table 20.UG-2). Again, as for the conducted susceptibility test, for simplification the limits have been combined resulting in some over testing in some frequency bands.

When dealing with the categories for radiated susceptibility testing which are derived from constant attenuation figures, it is permissible to select different categories for different frequency bands depending on the expected (or measured) attenuation of the aircraft location where the equipment is to be installed.

Table 20.UG-2: Category Definition for the Radiated Susceptibility Test in Terms of Location on the Aircraft and the HIRF Environment

Expected attenuation	Rotorcraft Severe Environment (HIRF Environment III)	Certification Environment (HIRF Environment I)	Normal Environment (HIRF Environment II)
0dB	L	G	G
6dB	L	F	F
12dB	G	D	D
18dB	F	B	B

New threats for avionics that have been recently studied are Transmitting Portable Electronic Devices (T-PED). These are specific in the fact that these sources of disturbances can be brought internally to the aircraft. Guidance from RTCA DO-307 Change 1, Section 3, and ED-130 may be followed in choosing appropriate test levels relative to T-PED tolerance. CAT R and CAT W may be appropriate as described in RTCA DO-307. Additional analyses may be required, as described in ED-130. In such cases, ED-130 provides data for such analyses.

20.UG.3

General Test Requirements

Section 20.3 provides some guide-lines on the general test set-up. These are intended to aid test repeatability but are somewhat brief and are therefore expanded in this section.

a. Equipment Under Test (EUT)

(1) Ground Plane

For the bonding of the ground plane to the shielded enclosure, not only the distance between the bonding strips and their resistance is important, but also the position and the orientation of these strips contribute considerably to field distribution into the room. Experience has shown influences up to 20dB at some frequencies during radiated emission test.

It is suggested, when testing in anechoic chamber, that the bonding strips at the back and on both sides of the test table be lead horizontally to the sidewalls of the shielded enclosure in order to minimize reflections.

(2) Shock and Vibration Isolators

The EUT should be mounted on the test bench in a manner that would cover the worst aircraft configuration from the aspects RF coupling to the equipment. This is particularly important when the results of the conducted and radiated susceptibility test are to be used to aid aircraft certification.

(3) Electrical Bonding

It is first necessary to verify that the bonding of the EUT to the ground is at least, from a resistive and inductive point of view, no better than what can be achieved on the aircraft installation.

This will insure that all filtering and surge suppressors in the EUT are installed (i.e., grounded) similar to the aircraft installation and will be tested in an environment that is not “better than” the aircraft installation, if known.

(4) Interconnecting Wiring/Cables

It is necessary to verify that the wiring harness lay-up is not providing better shielding protection in comparison to what can be achieved on the aircraft. The same type of wiring should be used in terms of twisted pairs (number of twists per meter, dielectrics and gauge) twisted shielded pairs (type of shield), coaxial cables etc. The connection of the shield should not be better than what will be achieved on aircraft according to the equipment manufacturer's recommended installation guidelines. A typical example is length of pig tail shield connection when used.

If the final aircraft installation is not known or the equipment is to be installed on a variety of aircraft, the test installation should cover the worst case allowed by the equipment manufacturer's recommended installation guidelines.

From a test set-up point of view, the cable bundle arrangement can influence the injected current distribution produced during the test.

A BCI test configuration with all bundles grouped, except at the injection point where only one bundle at a time is tested, may increase the Bulk Current Injection (BCI) current return flowing in the adjacent bundles. A configuration with bundles separated all along the set-up will produce more return current into the ground plane, which is how the test was first envisioned.

The EUT arrangement used for the test should be accurately described in the test report. This includes management of the configuration of the equipment in such a way that modification status of the equipment, cable lay-up and shielding arrangements are accurately traced. This is important to enable the airframe manufacturer to ensure the intended aircraft installation is adequate. A photograph of the test set-up in the test report is helpful in determining the test conditions and aiding repeatability if a re-test is required, and should be included where practical.

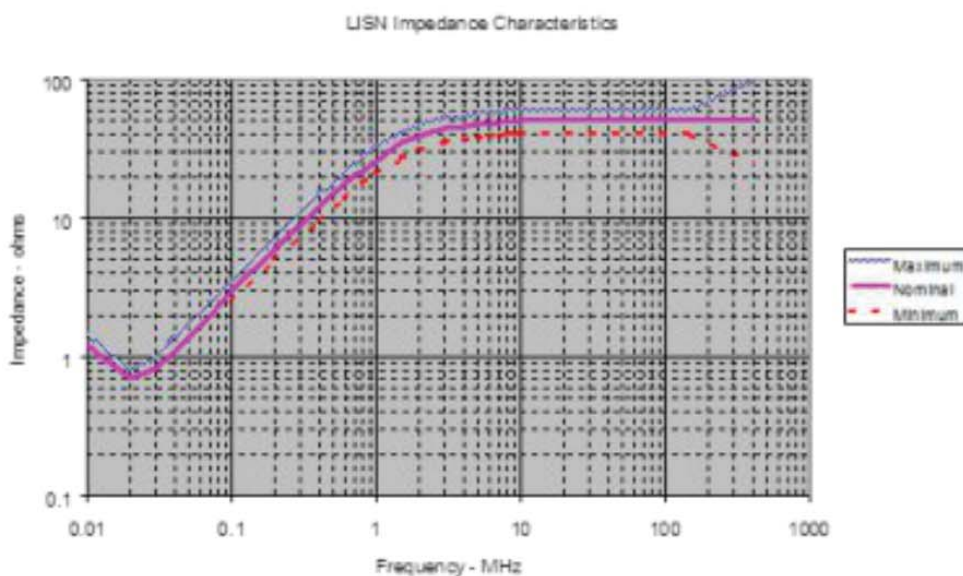
(5) Power Leads

In some cases, Line Replaceable Units (LRUs) will condition the power received from the aircraft power system before passing it on to power other equipment within the same system. For EUTs using such conditioned power those power lines and returns should be assessed as interconnecting bundles. The power return should be treated as signal ground, as described in section 20.3 a (5). Examples include In Flight Entertainment system head controllers that convert 115 VAC aircraft power, and converting it to 5 VAC power used to power individual downstream In Flight Entertainment modules. Conversely, when an EUT receives power that is simply passed to the EUT through an intermediary LRU between the power system and the EUT, those power lines and returns should be treated as power leads. Examples include Flight control systems that receive 115 VAC power and pass it, unconditioned, onto downstream sensors. Remotely controlled and/or electronically controlled circuit breakers are typically considered to be part of the aircraft power system, and EUT power lines and power returns conducting current from those circuit breakers should be treated as power leads.

b. Shielded Enclosure and Test Equipment

(1) Line Impedance Stabilization Network (LISN)

A Line Impedance Stabilizing Network (LISN) is placed in each primary power line and each power line return that is not a local ground. The purpose of the LISN is to provide defined RF source impedance for the test house power supply (Figure 20.UG-1). The design of the LISN was removed from section 20 since the “E” revision although the impedance characteristic definition has not changed.



Note: No minimum impedance limit is specified below 100 kHz.

Figure 20.UG-1: LISN Input Impedance

The design provided in DO-160 issue C is still valid and there is no basic change in the required design other than the removal of the lower limit at low frequencies. The inductor used is 5 μ H not 50 μ H as specified in MIL-STD-461/462D.

The 50 ohm coaxial load for all Section 20 tests should have a power rating of at least 100 watts for the higher equipment categories during the conducted susceptibility (CS) test.

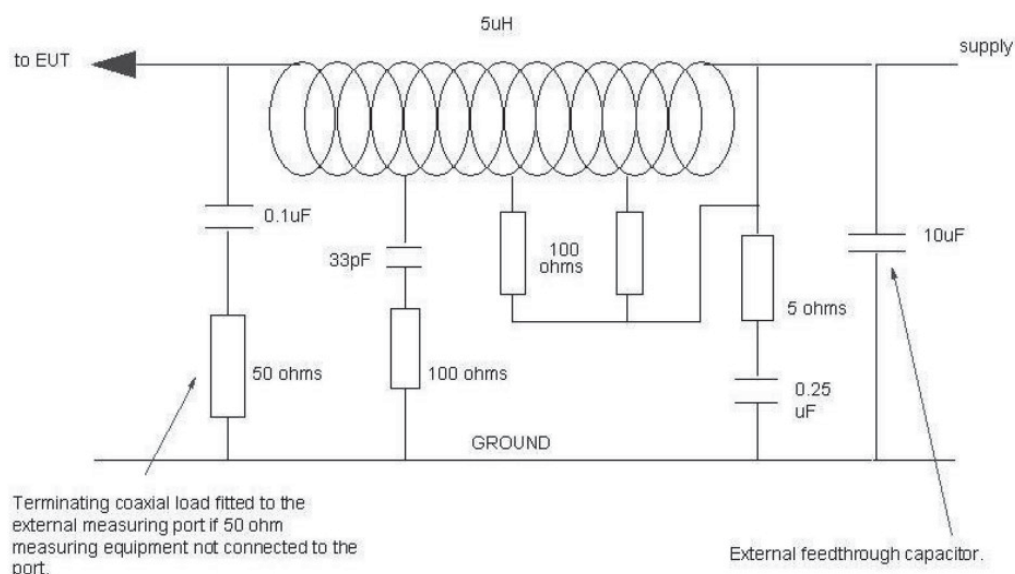


Figure 20.UG-2: Representative Schematic Diagram for the Line Impedance Stabilizing Network

The coaxial load is shown connected in Figure 20.UG-2. The 10 μ F capacitor shown on the supply side of the LISN, as required in section 20, will provide for more repeatable results as the length of cable from the LISN to the shielded room wall is not specified. It also reduces the RF currents induced during the BCI test flowing into the shielded room supplies or onto other power supply lines. If this capacitor is not embedded in the LISN circuits itself, it would be recommended to use an external feed through capacitor in order to maintain high performance at high frequencies. The various components in the LISN need to be capable of handling the RF power which they will dissipate during the Bulk Current Injection (BCI) test. The resistors in the unit need to be at least two watts.

(2) Injection Probes

An aspect of installations often overlooked, which can cause significant errors is shown in Figure 20.UG-3.

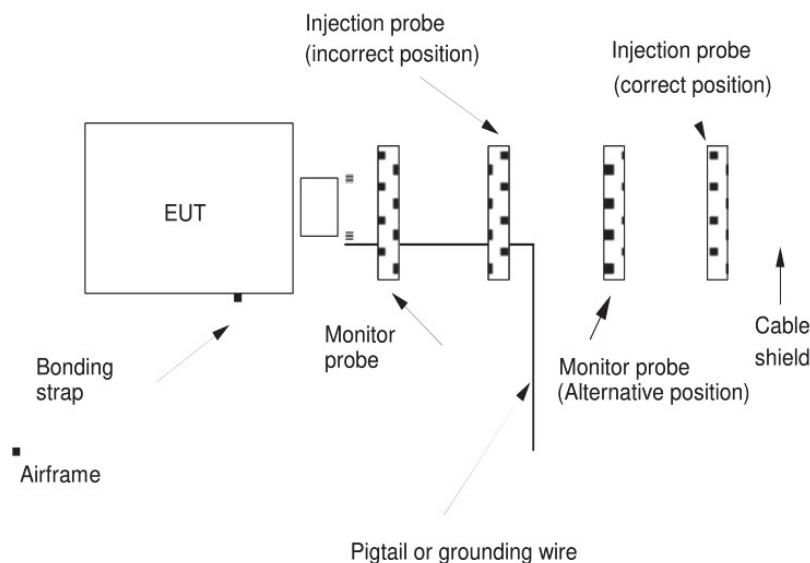


Figure 20.UG-3: Conducted Susceptibility Test Problem Caused by Pigtail or Ground Wire

In many installations a short wire is run either from the connector back shell to ground, or from a grounding point inside the box, through a pin to ground. If the test is only conducted when the injection probe is placed around this lead as well as the total bundle, misleading results at lower frequencies ($<100\text{MHz}$) will be obtained as this wire acts as a short circuit carrying most of the induced current. This would not happen when the EUT is installed on the aircraft and the aircraft is subjected to a radiated field. The currents induced at malfunction of the equipment during Conducted Susceptibility (CS) tests can be typically an order of magnitude higher than those that would be produced by the radiated field.

The injection probe should be placed in addition around the bundle excluding this wire as shown in the diagram. When using generic curves and if this wire is a grounding wire for the cable shields and is not bonded to the equipment case or connector then it should be excluded from both the monitor and injection probe. This is because it can give rise to over testing by giving low induced current readings by cancelling out the induced currents on the shield.

(3) Shielded Enclosure

When reverberation chamber techniques are not used, the use of RF absorber material is mandatory in the specification during radiated testing in order to reduce reflections and aid in test consistency. As a minimum it should line the shielded room walls above, behind and on both sides of the EUT and the walls behind and to each side of the radiating antenna. The minimum requirement for the anechoic lining used is defined in section 20.

This requirement is based on MIL-STD-461/462D and is not particularly onerous. During radiated susceptibility testing it has been found that by placing multi layered anechoic slabs such as AN 79 around the antenna, a more consistent load is presented to the driving power amplifier.

This is because the coupling of the antenna to the shielded room is minimized. This coupling manifests itself in resonances in the VSWR characteristics of the antenna.

Any test equipment and sensors which are implemented in the set-up for monitoring purpose only should be interfaced to the EUT by fiber optics. This helps to provide susceptibility-free monitoring of the EUT and prevents spurious resonances in the coupling of RF to the EUT's wiring bundles.

Any test loads or simulated test signals should reflect the final installation in terms of signal type and impedance. This will have to include all impedances from load filtering or protection devices. They must not contribute to the overall susceptibility of the EUT and therefore may need hardening.

c. Amplitude Measurement

Confusion has existed amongst some engineers as to the definition of the test limits when dealing with modulated signals. This confusion has also surrounded the measurement units used to define the field strength of the HIRF environment.

The various HIRF environments and associated susceptibility test levels are defined in terms of the "peak of the rms envelope" (peak rms) of the signal. This is in terms of electric field strength (V/m) for both the environment and the radiated susceptibility test levels.

The electric field strength values of the HIRF environment have been determined from the measured or calculated values of the power density produced by the various transmitters, either average for CW fields or peak for modulated fields:

The field strength (E) from the transmitter assuming far field conditions is:

$$E = (Pd * 377)^{1/2} \text{ [V/m]}$$

where Pd = power density [W/m²];

$$Pd = (\text{Transmitter Power} * \text{Antenna Gain}) / (4 * \pi * \text{Distance}^2)$$

The field generated by an unmodulated transmitter is expressed in terms of power density and the peak and average values are the same. In plane wave conditions, this is equal to the product of the electric and magnetic fields. In all cases we are talking about the rms values which, as in all forms of electrical engineering, have always been true electrical peak divided by root 2.

When dealing with modulated signals such as pulse modulated fields from radar, there is obviously a difference between peak and average values of power density. The ratio between the peak and average values is a function of the duty cycle with pulse modulated or gated signals. For instance, with a duty cycle of 50%, e.g. on for 50% of the time and off for 50% of the time, the average value of field strength is 3dB lower than the peak value.

Under plane wave conditions, the power density is still a function of the product of the electric and magnetic field strengths. In the case of the peak field it is the product of the rms value of the electric and magnetic field strengths for the time that the signal is on (Figure 20.UG-4, Figure 20.UG-5). When the signal is off, the field strength is obviously zero.

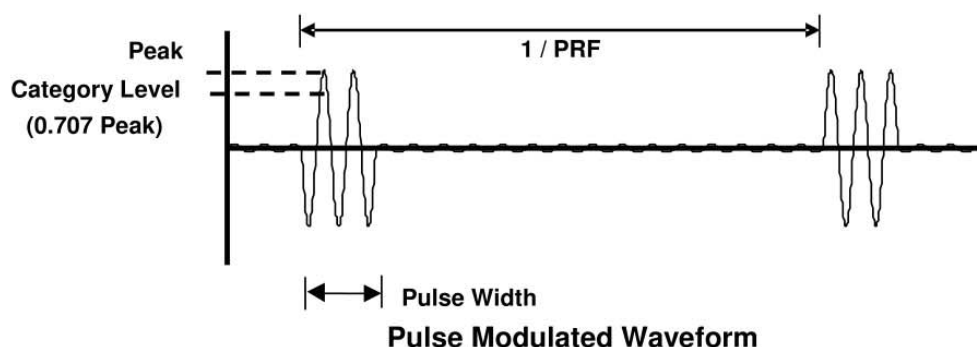


Figure 20.UG-4: Pulse Modulated or Gated Signal

When dealing with more complex amplitude modulated signals, the peak field strength is expressed in terms of the maximum instantaneous value of power density, which equates to the product of the maximum instantaneous rms values of the electric and magnetic field.

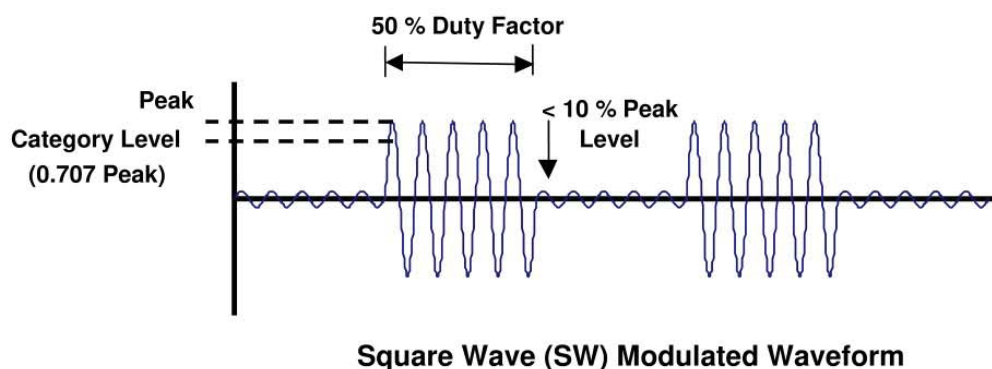


Figure 20.UG-5: Amplitude modulated waveform

The term maximum instantaneous rms value has become known as peak rms and is the normal parameter measured during equipment and aircraft EMC tests; hence commonality with the way the peak HIRF environment is expressed.

All measurements relating to HIRF are made using the peak detector function of the measuring receiver/spectrum analyzer. This is calibrated in terms of the equivalent rms value of a sine wave. What does this mean? When measuring a modulated signal, the bandwidth of the measuring receiver should be set wide enough to capture the total energy of the signal. The amplitude reading as measured by the peak detector function is noted. The unknown signal is disconnected and a sine wave signal at the same frequency fed in. Its amplitude is adjusted until the same reading is produced on the measuring

receiver. This amplitude is expressed in terms of the rms value of the sine wave e.g. a 1 volt rms sine wave input will give an indicated measurement of 1 volt. This will not change if the signal is switched on and off, the peak reading will still be 1 volt hence the term peak rms.

It is important to meet these requirements especially when measuring modulated signals. The use of a spectrum analyzer for signal measurement during susceptibility testing does provide advantages over power meters or receivers as it allows a more direct visual check on the quality of the applied signal during the testing. It provides direct indication if the signal source is becoming non-linear, or generating spurious signals. Sometimes, when mismatched, TWT amplifiers have been found to produce parasitic high power oscillations even with no input drive at a frequency, which may be well removed from the required test frequency. Regular checks should be made on the quality of the test signal, and presence of spurious signals.

The forward power pulse modulated measurement can provide erroneous results depending on the technique used. High power TWT amplifier output has been shown to have leading edge ringing and other artifacts which need to be understood before performing automatic measurements. [Figure 20.UG-6](#) is a plot of the detected output of a TWT pulsed amplifier from the test setup shown in [Figure 20.UG-7](#). The frequency synthesizer drives a CW signal into a TWT amplifier which is gated by a pulse generator. The pulse generator outputs a 10 μ s pulse width with a 1 kHz pulse repetition rate to the gate input of the TWT amplifier. A peak power head is connected to the forward port of a directional coupler on the output of the amplifier. The peak power head besides being connected to the power meter has a feature which provides a detected output which can be viewed on an oscilloscope. Channel 1 of the oscilloscope is the detected output from the power head. Channel 2 is the sample delay pulse from the power head.

The oscilloscope automatic measurements of channel 1 is listed under the scope waveforms show the variation in amplitude measurement. The “maximum” reading measures the highest point of the front edge overshoot which is incorrect. The “top” reading measures the level beyond the initial reading and is a representation of the desired measurement.

The falling edge of trace 2 indicates where the reading on the power meter is taken. There is also a tick marker on trace 1. The measurement point is adjustable by setting the delay from the trigger point. To get a stable pulse measurement, the reading should be taken beyond the initial leading edge ringing of the waveform.

There are other types of peak power measurement equipment which have similar features that will display the detected output in the time domain so that the fidelity of the waveform can be observed in order to make a correct reading. A peak power measurement using an average measurement and applying a mathematical equation to derive the peak value can produce erroneous results if the fidelity of the waveform parameters differs from an ideal pulse. As an example, the forward power pulse width may have little distortion whereas the pulse measurement readings from the receive antenna within a reverberation chamber can be extremely distorted and a mathematical calculation based on an average measurement would be incorrect.

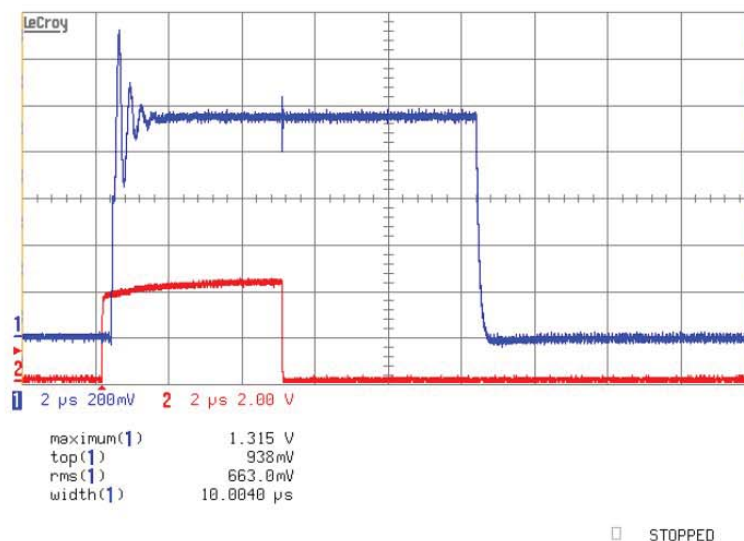


Figure 20.UG-6: Pulsed Susceptibility Forward Power Measurement, Ringing on Leading Edge

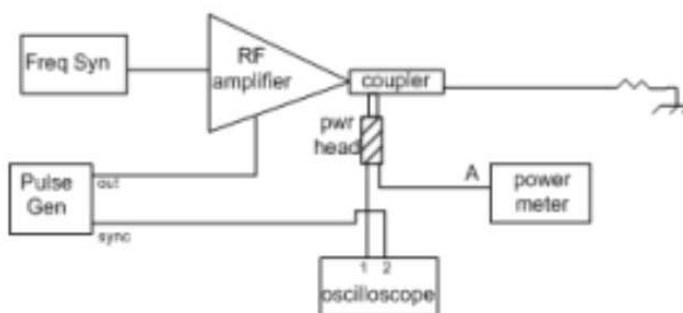


Figure 20-UG.7: Pulsed Susceptibility Forward Power, Ringing on Leading Edge Test Setup

One method to reduce leading edge ringing on the output of TWT pulse amplifiers is shown in Figure 20.UG-8. Figure 20.UG-9 is a plot of the detected output of a TWT pulsed amplifier from that test setup. The frequency synthesizer drives a pulsed modulated signal (PW 10 μ s, PRF 1 kHz) into a TWT amplifier which is gated by a pulse generator. The pulse generator outputs a 14 μ s pulse width with a 1 kHz pulse repetition rate to the gate input of the TWT amplifier. The pulse generator output also triggers the output of the frequency synthesizer which is delayed by 2 μ s. The pulse generator sync output triggers the peak power meter head measurement. Basically, the TWT amplifier is gated for a longer duration than the pulse modulated input which is centered within the gate duration.

A peak power head is connected to the forward port of a directional coupler on the output of the amplifier. The peak power head besides being connected to the power meter has a feature which provides a detected output which can be viewed on an oscilloscope. Channel 1 of the oscilloscope is the detected output from the power head. Channel 2 is the sample delay pulse from the power head.

e. Frequency Scan Rates

When using test equipment that generates discrete frequencies, DO-160G defines the minimum number of test frequencies as 100 frequencies per decade. The test frequencies shall be logarithmically spaced. DO-160G gives an example of a formula that can be used to calculate these frequencies in ascending order:

$$f_{(n+1)} = f_n * 10^{\left(\frac{1}{100}\right)}$$

where f_n is the test frequency and $n = 1$ to m

f_1 is the start frequency

f_{100} is the end frequency

$m = 1 + 100 * \log(f_m / f_1)$ rounded up to the nearest integer

If the last test step for f_{n+1} yields a frequency greater than f_m , then set the last frequency to f_m

For ease of use, Table 20.UG-3 shows the results of this calculation assuming a start frequency of 1, e.g. the results are in MHz if the start frequency is 1MHz. In this instance the first start frequency is 1MHz and the final 100th test frequency in the decade is 9.7723MHz.

If the start frequency of the decade is 100MHz, multiply the frequency given in the table by 100 and the result will be in MHz.

Table 20.UG-3: Test Frequencies for 1 Decade

N	Freq	N	Freq	N	Freq	N	Freq	N	Freq
1	1	21	1,5848	41	2,5118	61	3,98107	81	6,3095
2	1,0232	22	1,6218	42	2,5703	62	4,07380	82	6,4565
3	1,0471	23	1,6595	43	2,6302	63	4,16869	83	6,6069
4	1,0715	24	1,6982	44	2,6915	64	4,26579	84	6,7608
5	1,0964	25	1,7378	45	2,7542	65	4,36515	85	6,9183
6	1,1220	26	1,7782	46	2,8183	66	4,46683	86	7,0794
7	1,1481	27	1,8197	47	2,8840	67	4,57088	87	7,2443
8	1,1748	28	1,8620	48	2,9512	68	4,67735	88	7,4131
9	1,2022	29	1,9054	49	3,0199	69	4,78630	89	7,5857
10	1,2302	30	1,9498	50	3,0902	70	4,89778	90	7,7624
11	1,2589	31	1,9952	51	3,1622	71	5,01187	91	7,9432
12	1,2882	32	2,0417	52	3,2359	72	5,12861	92	8,1283
13	1,3182	33	2,0892	53	3,3113	73	5,24807	93	8,3176
14	1,3489	34	2,1379	54	3,3884	74	5,37031	94	8,5113
15	1,3803	35	2,1877	55	3,4673	75	5,49540	95	8,7096
16	1,4125	36	2,2387	56	3,5481	76	5,62341	96	8,9125
17	1,4454	37	2,2908	57	3,6307	77	5,75439	97	9,1201
18	1,4791	38	2,3442	58	3,7153	78	5,88843	98	9,3325
19	1,5135	39	2,3988	59	3,8018	79	6,02559	99	9,5499
20	1,5488	40	2,4547	60	3,8904	80	6,16595	100	9,7723

f. Data Required

Section 20 defines data that must be included in the test report, including pass/fail criteria. It is important to note that the pass/fail criteria for showing compliance of equipment to the T-PED RF environment may be different from that used for the HIRF

RF environment. The T-PED RF environment can be considered “steady state” whereas the HIRF RF environment is considered “momentary”.)

20.UG.4 Conducted Susceptibility (CS) Test

a. Applicability/Intent

The purpose of this test is to ensure that the EUT is immune to the effect of RF currents induced onto its cable bundles as a result of exposure to airframe internal and external RF fields. This test is based on injecting RF currents into the EUT's wiring by means of a current probe. The test is intended to ensure non-susceptibility from:

- Signals conducted from the power system
- Signals conducted from connected LRUs
- Radiated fields

The bulk current injection technique, as reflected in section 20, was developed to provide better repeatability and a more representative test than that provided by the radiated susceptibility test below 100 MHz. Results from this test can be used directly to aid final aircraft certification. This test can provide an amplitude/frequency malfunction signature in terms of induced cable bundle current for the EUT. The basic test consists of injecting RF currents onto each of the EUT's cable bundles one at a time, while measuring both the forward power fed to the injection probe and the resultant induced current. Each cable bundle is typically associated with a unique connector on the EUT. If the power return is a local ground, then the power ground should not be included in the injection probe during the test. Power lines should be tested as bundled in the intended installation. If the aircraft configuration is unknown, the power wires should be routed and tested separately.

In revision E and earlier, two different procedures were required for conducted susceptibility testing dependent on equipment category. Following the introduction of revised categories in revision F a single procedure now applies. The primary limit is in terms of induced current on the wiring bundle under test with the secondary limit being in terms of the forward power to the injection probe. The reason for the change is to ensure a common approach to all systems which allows comparison with on aircraft induced cable bundle current measurements.

The test is applicable to all cable bundles, which connect the EUT to other equipment in the aircraft system including primary power lines or those interconnecting units of the EUT. Additionally, the relevant aircraft manufacturer's EMC specialist may select some individual wires, apart from power lines, for test.

Redundant Systems – Multiple Injections

Where a system has built in redundancy, e.g. a quadruplex flight control system, simultaneous injection on several bundles may be required. This would normally be on the identical connector port in each lane. If this is not done, then redundancy management logic (channel voting) may mask disturbances of the system. If it is not possible to inject RF at the same time on all channels using one probe, multiple simultaneous injections may be considered.

Reconfigurable Redundant Systems

If the EUT is built with a reconfiguration process in case of failure, it is important to test all configurations or to test at least the most critical configurations including the normal

and last available (with all redundancies off) configurations. To give an example, one system architecture used for engine control is as follows:

Typically an EUT with embedded redundancy will be provided with two identical channels, one control and one monitoring. A back-up degraded mode may be used when unacceptable discrepancy is detected by the monitoring system.

Simultaneous injection with separate probes on several bundles may be used, and may be required for equipment with built-in redundancy. (Reference SAE ARP 5583A / EUROCAE ED-107)

- If it is not possible to inject RF at the same time on all channels with one probe, multiple injections may be used.
- If the EUT is built with a reconfiguration process in case of failure, it is important to test all configurations or to test at least the most critical configurations including the normal and last available (with all redundancies off) configurations. To give an example, one system architecture used for engine control is as follows:

Typically a EUT with embedded redundancy will be provided with two identical channels, one control and one monitoring. A back-up degraded mode may be used when unacceptable discrepancy is detected by the monitoring system.

In such case two test configurations can be identified:

- Normal configuration
- Reconfigured configuration (e.g. failed freeze mode for a FADEC).

In each configuration, it is necessary to identify if multiple injection is required. In the example cited above, configuration (i) could require multiple injections and (ii) would not.

Figure 20.UG-10 shows such an example of a simple case where a single injections rather than multiple would be applied. The reason for this is that there is no redundancy even though there are multiple bundles.

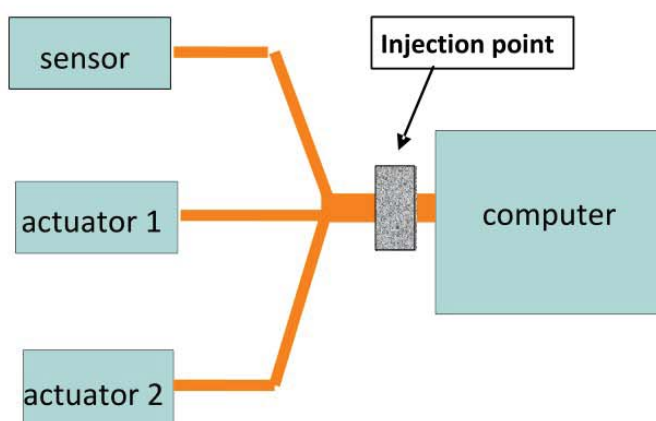


Figure 20.UG-10: Single Injections Required

Figure 20.UG-11 requires simultaneous injections at positions 1.

In all cases, detailed HIRF system hazard analysis by the systems integrator is required to determine all test cases to be conducted by each equipment manufacturer.

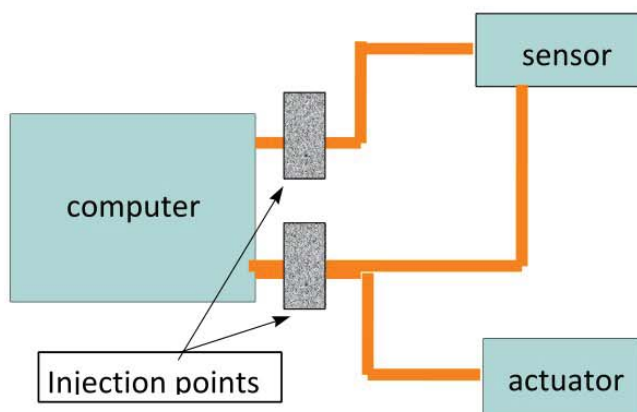


Figure 20.UG-11: Multiple Injection Points with Dual Channel Injection

Computer control is essential to control the injected power in each channel. A single signal source is used with modulation being added prior to the signal being split into separate channels.

Comment has been made about the importance of the phase relationship of the injected signal in each of the individual injection channels at the carrier frequency. The phase shift of the carrier need not be considered in the test parameters. The dominant concern is to ensure that the modulation is in phase in all the injection channels for this test, as will be the case in "real life".

b. Probe Calibration

Figure 20.UG-12 shows the required test set-up for calibration. No design for the calibration jig required for this part of the test is given and it is a critical component in the final test accuracy. One design is shown in Figure 20.UG-14.

The forward power to the injection probe is gradually increased, and the level recorded, to provide a current in the calibration jig equivalent to the induced current test level defined in section 20. It is important that the directional coupler used to measure the forward power has high directivity across the complete frequency range of the test to ensure the forward power is accurately measured as the injection probe can present a high VSWR at some frequencies. To keep errors below 1dB, the coupler should have a directivity of >20dB over the frequency range of the test. The forward power to induce the defined current is recorded for use during the injection test although for the injection test the primary limit is in terms of the defined current with a power maximum of 6dB (4 times) the forward power measured during the calibration.

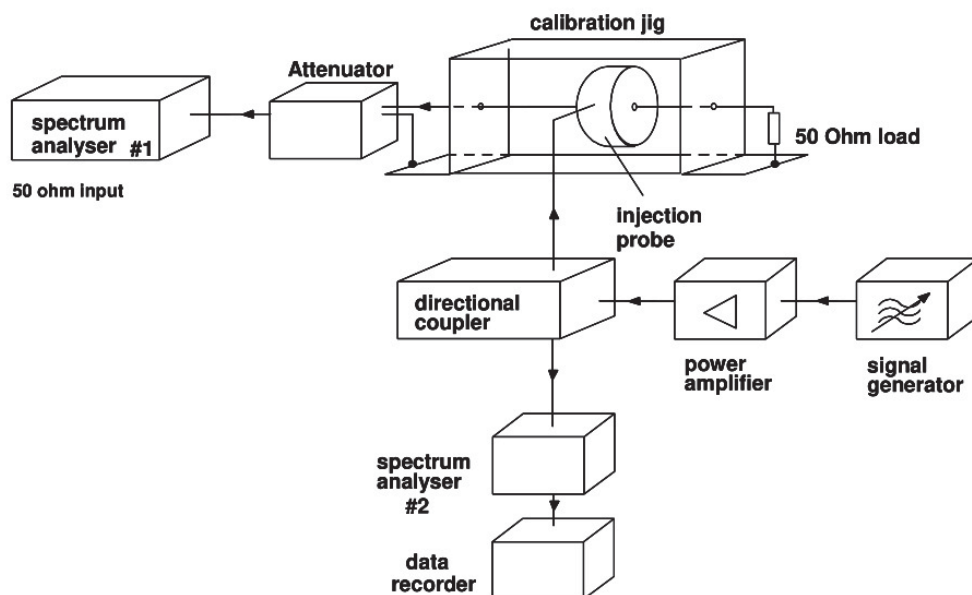


Figure 20.UG-12: Bulk Current Injection Calibration Set-Up

The calibration should be conducted with the same test set-up that the actual injection test will use, e.g. the same location of test equipment, same cables and bonding arrangements. The injection probe should be isolated from the case and center conductor of the calibration jig by insulators. Ferrite loading may be used on the cable to the injection probe to prevent spurious cable resonances affecting the probes performance. This loading is performed by placing large ferrite beads along the length of the screened cable to the injection probe. They must be effective at the frequency at which the cable length is $\lambda/2$. These resonances are more noticeable if the cable to the injection probe is of similar length as the cable under test and show up as resonances in the induced cable current during the CS test.

Figure 20.UG-13 shows the specified maximum and minimum values of insertion loss for the injection probes covered by two injection probes with a changeover frequency of 5MHz.

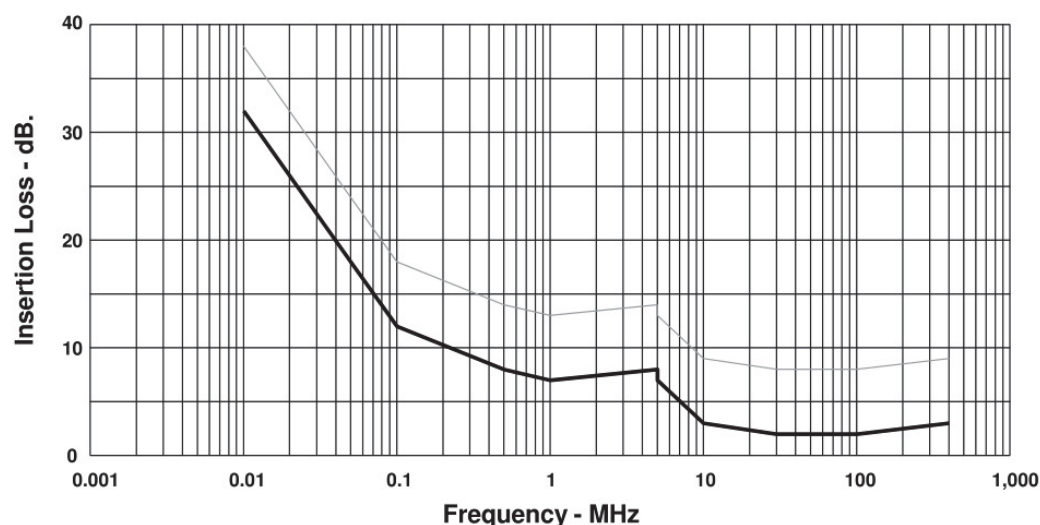


Figure 20.UG-13: Specified Insertion Loss of the Injection Probes

The insertion loss is specified in terms of the ratio of the received power at the spectrum analyzer compared with that applied to the calibration jig. Whatever probes are selected for the test, they should conform to the insertion loss values shown in 13 and should behave as expected if in correct operating region for the core e.g. increasing the input power by a factor of 4 will increase the induced current by a factor of 2. To express it in dB terms, a 6dB increase in input power will lead to a 6dB power increase in induced current.

It is important that the temperature of the injection probe is monitored during the test to prevent thermal runaway causing the probe core to pass its Curie Point resulting in non-linearity.

The power amplifier used to drive the injection probe must be capable of linear operation when feeding a severe mismatch. The injection probes present a high VSWR load over parts of the frequency range, and amplifiers which operate in Class B or containing electronic protection against high VSWR loads are likely to produce highly distorted signals when driving the injection probes. Care must therefore be shown in amplifier selection.

The main areas of error which could affect test accuracy would on first glance appear to be the effects of isolating or grounding the calibration jig, bonding of cables to the calibration jig, variation of probe position within the jig itself and the design of the calibration jig.

If the injection probe comes into electrical contact with the calibration jig then significant variations could occur. To overcome this problem the center conductor and the inside faces of the jig must be insulated from one another.

Any errors in the performance of the calibration jig directly affect test accuracy. It is important for the top cover plate to be fitted and in good contact with the rest of the calibration jig to enable repeatable calibrations to be performed.

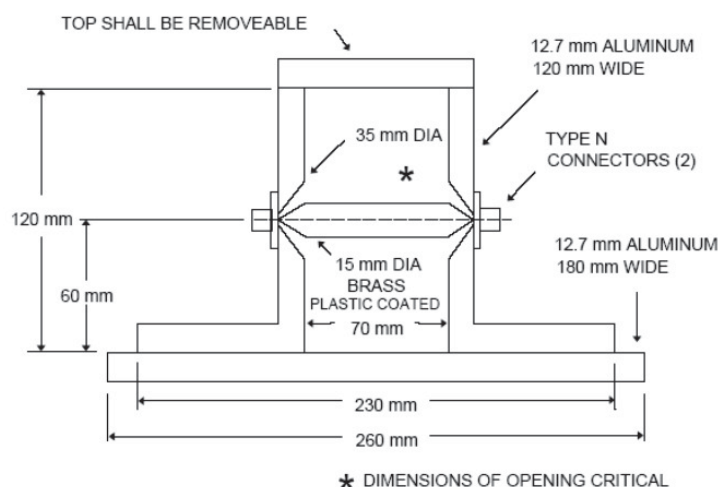


Figure 20.UG-14: Bulk Current Injection Test - Recommended Calibration Jig Design (ref. MIL-STD-461E)

The required VSWR of the calibration jig was added in an update to the “C” revision and subsequent revisions of DO-160 and is reproduced below in [Figure 20.UG-15](#).

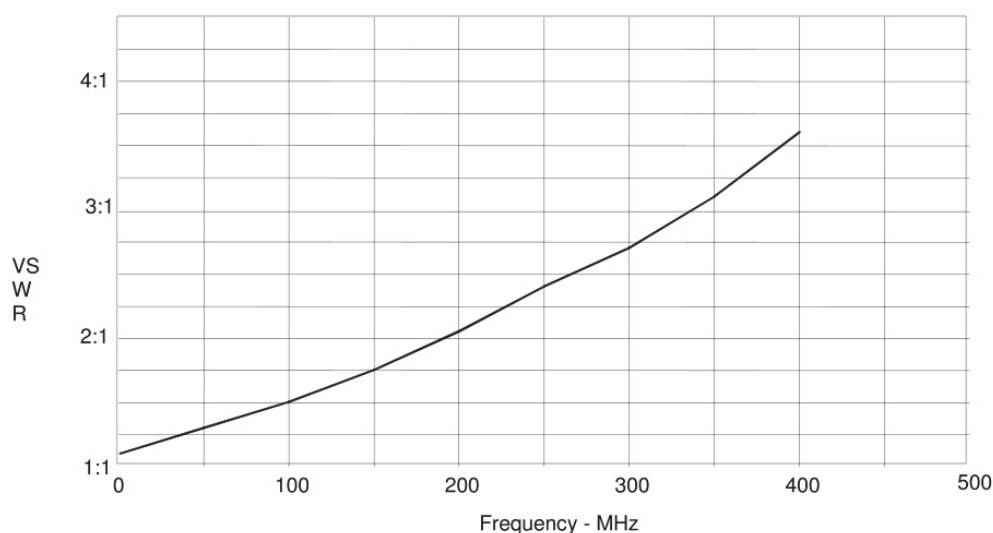


Figure 20.UG-15: Calibration Jig Maximum VSWR Limit

The probe should be mounted centrally in the calibration jig to minimize variations and be insulated from all parts of the jig including the cover plate.

The injection probe calibration will be significantly affected if the probe overheats to such an extent that the ferrite permeability is affected. This can significantly reduce the coupling between the probe and the calibration jig or the bundle being tested. The degree of degradation depends on the temperature of the core. This is a runaway situation with the core's increasing inefficiency and losses accelerating the temperature rise. It is

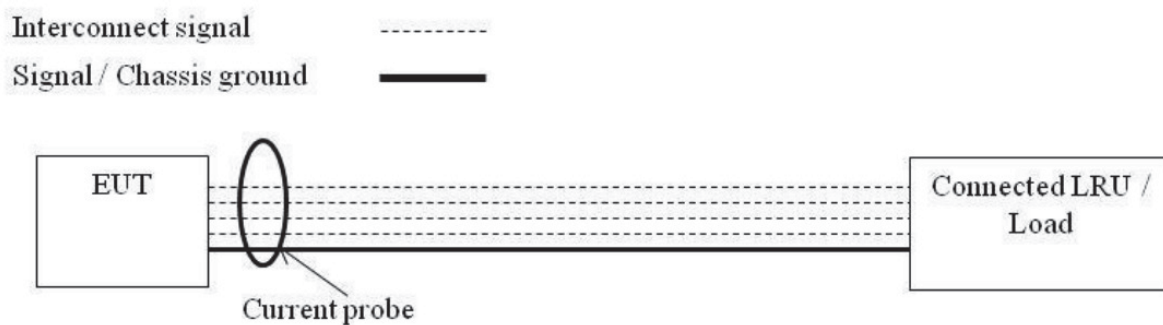
therefore essential when testing at the higher equipment Categories to monitor the probe temperature.

c. CS Test Setup

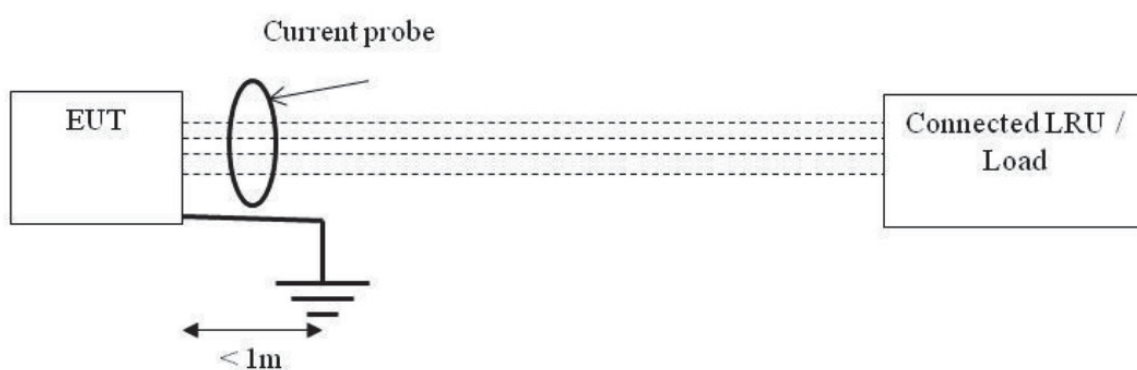
Table 20.UG-4 is intended as a guide for typical bundling/testing: Generally, power (high) wires should not be bundled/tested with their power return wire because the inclusion of a low-impedance power return will drain the test current, potentially resulting in less current induced on the power (high) than would be conducted from the power system in an actual aircraft installation. An important aspect of determining which wires to include within the current probe is to ensure low-impedance wires that are not normally routed with the interconnecting bundle for the most significant part of the bundle length are not included with the interconnect bundle under test. Some examples are shown in Figure 20.UG-16.

Table 20.UG-4: Wire Bundling/Testing

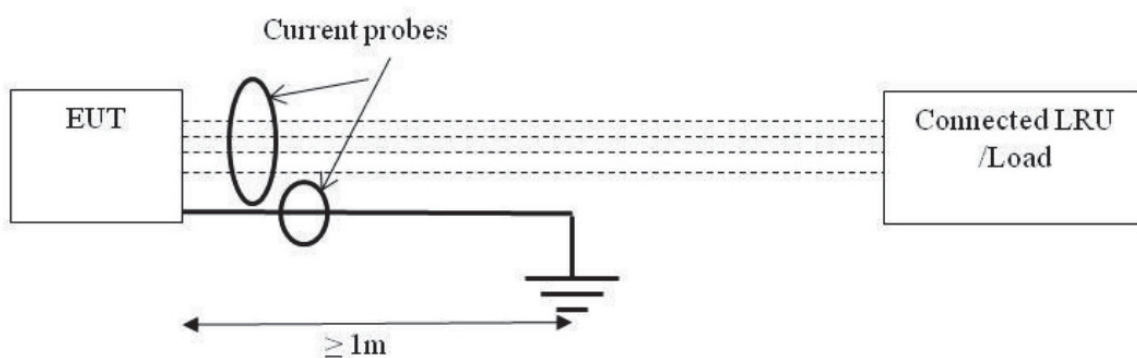
			CS testing	RS bundling
Power leads	Highs		Test individually	Bundle separately unless installation is known to bundle together
	Returns	<1m	No test (reference 20.4a)	
		≥1m	Test as separate bundle(s)	
Interconnect wiring	Wiring to other LRUs, including their shields		Test separately, usually by connector or as multiple bundles	Bundle by connector unless installation is known to co-bundle wiring from multiple connectors
	Signal/Chassis wires grounded outside of the interconnect LRU	<1m	No test	
		≥1m	Test as separate bundle(s)	



a) Signal / chassis wire grounded at connected LRU



b) Signal / chassis wire grounded within 1 meter of EUT



c) Signal / chassis wire grounded greater than 1 meter from EUT (Typically, such grounds are not co-routed with the interconnect wires)

Figure 20.UG-16: Wiring Inclusion within Current Probe

Although not required by DO-160G, the following procedure may be used to check the set up and equipment for proper connections and calibrations. Set up the test equipment

as shown in Figure 20.UG-17. Set the signal generator to 10 kHz, un-modulated. Increase the amplifier power fed through the directional coupler to the injection probe at 10 kHz until the stored calibration forward power level is measured on amplitude measurement instrument #2.

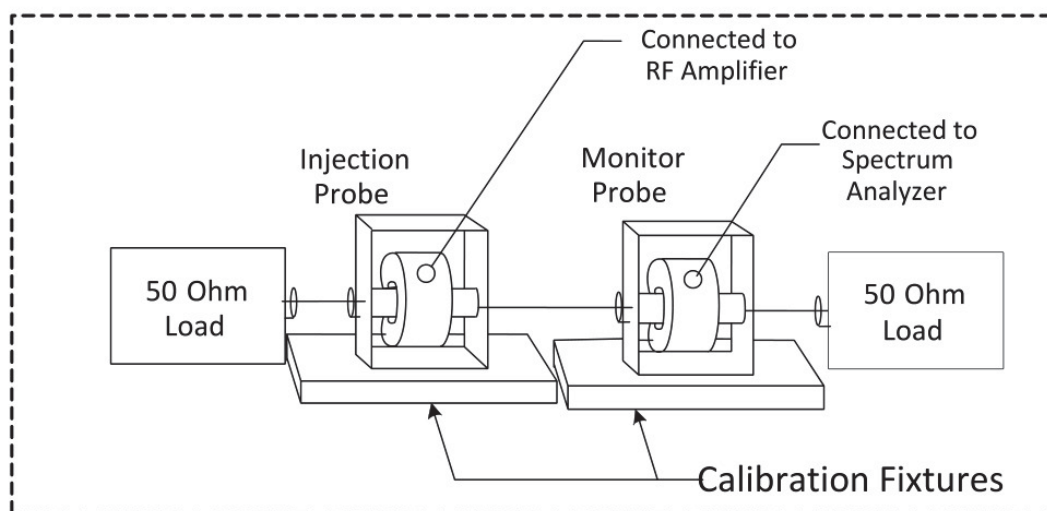


Figure 20.UG-17: Verification Setup for Conducted Susceptibility Test Section 20.4

CAUTION: RF fields due to re-radiation from the calibration jigs may be hazardous. Observe appropriate RF exposure limits.

Record the current level measured on the monitor probe.

Scan the frequency band (un-modulated) while recording the current measured by the monitor probe while maintaining the calibrated forward power levels to the injection probe.

The measured current should be within $\pm 3\text{dB}$ of the calibrated current level.

The VSWR of the attenuators and loads should be less than 1.2:1. The calibration jig VSWR without the probe installed should not exceed the values of DO-160G Section 20 Figure 20-8.

By running this system verification the following problems have been identified:

- Bad current monitor probe
- Current monitor factors in the software were not correct.
- Found that a bad 100 Watt 20dB attenuator was used during calibration (attenuation varied significantly and was out of tolerance over the frequency range).
- Bad directional coupler
- Bad RF cables

d. CS Test Procedure

Testing consists of 2 stages:

1. Calibration; measuring forward power to the injection probe to produce the required current in the jig.
2. Injection of the test limits current on the wiring bundle under test. The primary limit is in terms of the injected current. The secondary limit is 6dB above the power required to induce the test limit current in the calibration jig.

It should be noted that the primary limit in (b) is defined in terms of induced current rather than forward power to the injection probe

During the injection test, the current monitor probe, which is used to measure the induced current on the cable bundle or wire under test, is placed around the test cable 50mm from the EUT's connector. The injection probe is placed downstream of the monitor probe with a separation of 50mm between their adjacent faces. This separation distance is required to prevent direct coupling between the two probes.

In reality equipment/systems under test will be of varying complexity, incorporating multiple interface connections, power and signal, bifurcated or multi-branched harnesses/looming and multiple 'boxes' (Line Replaceable Items). Cable and monitor injection points will need to be predefined within the test plan, and where appropriate as determined by the aircraft manufacturer may include injection on multiple limbs of a branched cable.

Experience has identified problems due to limit overshoot when applying full forward power to cables at resonant frequencies. It may be recommended to start the test at a reduced power to limit the risk of encountering these problems. One method to deal with this concern above 500 kHz, when bundle may resonate, is to reduce the injected power by 12 dB at each frequency step in order to minimize the risk of problem due to limit overshoot. At each test frequency, the level of the forward power to the injection probe is gradually increased, from a level below that at which malfunction would be expected occur, until malfunction occurs or the test limit is reached.

The test limit is in terms of the induced current on the wiring bundle under test as defined by the appropriate category limit up to a forward power 6dB (factor of 4) greater than that which gave the required current in the calibration jig.

It is important to note that the power to the probe should be gradually increased to the limit to ensure that no malfunctions are missed through the "window effect". This is where it is possible to increase the power until an obvious malfunction apparently disappears due to circuit saturation. It is also necessary to ensure that a system has not "locked up" during testing.

Two parameters are recorded, the forward power to the injection probe and the induced cable bundle current. Complete frequency coverage should be obtained by slowly sweeping between each test frequency to ensure that the lowest susceptibilities have been found and the full malfunction signature is measured.

An optional measurement of "loop impedance" (not specified in section 20) can be performed to provide a characterization of the comparative "loop impedance" formed by the EUT, cable bundle and bonding straps for each bundle to be tested. It can be used as a quality control check if repeat qualification testing is required. It is a measure of the induced cable bundle current per unit forward power to the injection probe (record of the actual forward power and the actual current).

This test is performed on each cable bundle and wire to be tested prior to the actual injection test. It is a swept measurement of the induced current per unit forward power to the injection probe. The test configuration is shown in [Figure 20.UG-18](#).

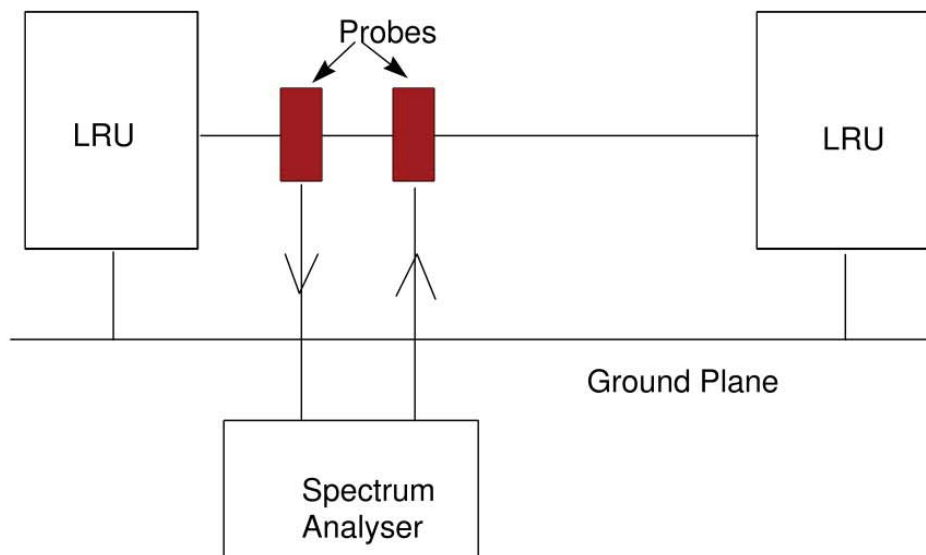


Figure 20.UG-18: Bulk Current Injection Test - Loop Impedance Measurement.

The position of the injection probe and monitor probe and their interconnecting cables are the same as for the injection test. The tracking generator output of the spectrum analyzer is used to feed power of the order of 1mW to the injection probe. The ratio of the injected current to the forward power is measured and normalized to 1 watt. The measurements should be graphically recorded.

The test is intended to provide information which can be used to compare repeat test installations or for comparison with the final installation on the aircraft to provide some information on how representative the final installation is to that used for the qualification test. In view of the fact that the installation used in the qualification test cannot accurately represent the final aircraft installation when in the majority of cases this is not known; the main purpose of the test is as a Quality Control (QC) check for repeat testing. Differences in the loop impedance measurement will be caused by variations in such parameters as:

- a. Equipment bonding
- b. Cable lay-up
- c. Cable screening and terminations
- d. Insertion loss of Injection/measurement probes used

The most obvious weakness in a test, which relies on injection and monitoring at discrete points on the cable bundle, is the effect of standing waves on the accuracy of the measurement or the coupling efficiency. One would expect this effect to be most pronounced if either probe is sited at a current node, as this is where the magnitude of the current changes most rapidly with position. This is true whether the line is lossy or loss-free. If the monitor probe is sited at a current antinode, the effect of moving it either side of this probe position is very much less. At 400 MHz, ignoring the velocity factor of the

wire under test, the amplitude variation can be calculated to be only 1dB for a 50mm movement from the antinode.

However the practical situation is complicated by the geometry and construction of the bundle being tested and the loading on that bundle of the injection probes. The high coupling efficiency of these probes means that they cause the signal source impedance to be transformed into series impedance on the lines or bundles being tested. Theoretical considerations are further complicated by the finite thickness of the injection or monitor probes as this means that they measure or inject over a finite width of the line or bundle under test.

Figure 20.UG-19 shows the coupling measured using a network analyzer between the injection probe and the monitor probe when these are placed around the 1m wire terminated to ground in a short circuit at one end and a $2.2\text{k}\Omega$ resistor at the other. The monitor probe is placed 50mm from the short-circuited end of the line and the separation between the injection and monitor probes varied from 50 to 100mm by moving the injection probe. In the figure, the dotted line shows the coupling for 50mm separation and the solid line 100mm separation. As can be seen, the main discrepancy in coupling between the measurements is above 200MHz with variations of up to 7dB.

When the measurements are repeated at the high impedance end, the variations in position cause a slight shift in the resonant frequency but the amplitude remains sensibly the same.

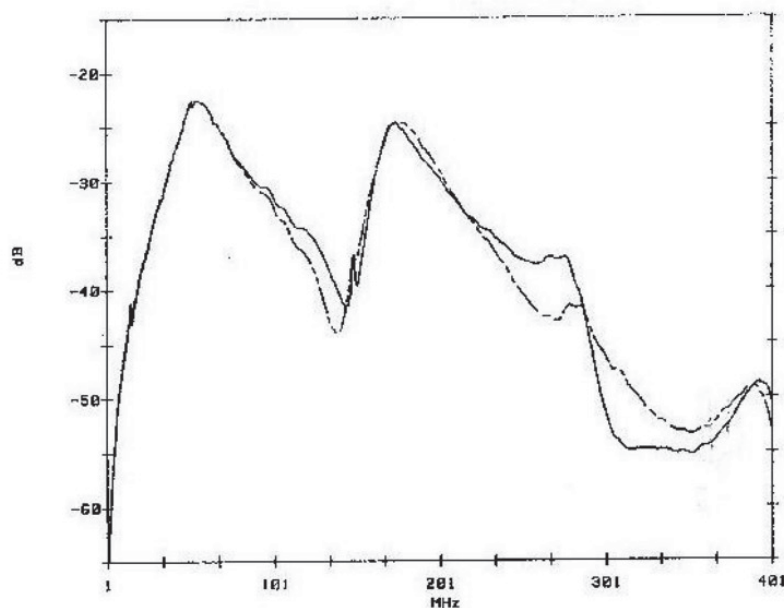


Figure 20.UG-19: Variation in Coupling by Injection Probe Movement on a Single Wire

Figure 20.UG-20 shows the same measurement made on the control bundle of the antenna transmitter unit of a Doppler navigation system. As can be seen, apart from a slight shift of resonant frequencies, the coupling is very similar.

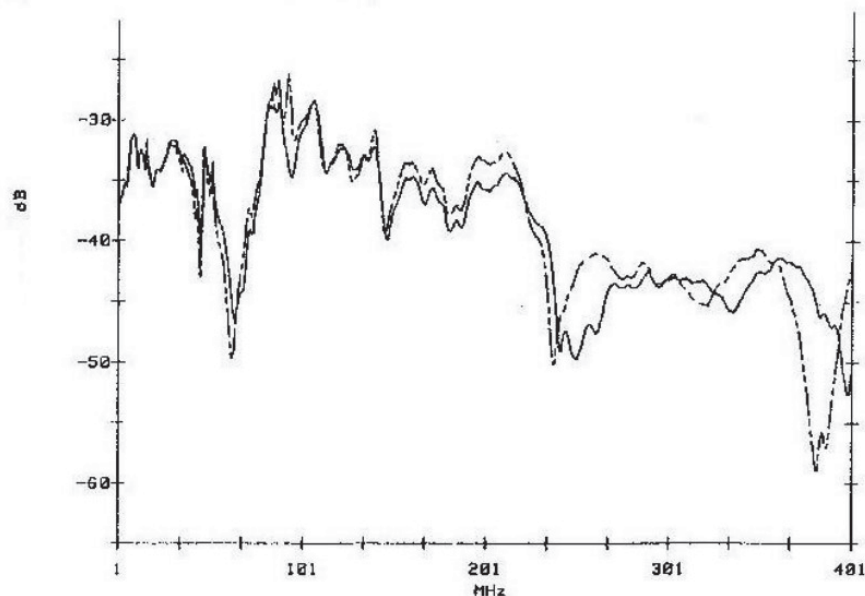


Figure 20.UG-20: Variation in Coupling by Injection Probe Movement on a System Harness

Figure 20.UG-21 shows the coupling between two probes around the same wire giving results shown in Figure 20.UG-19, terminated as before. The dotted line shows the coupling between the probes at 50mm separation and the solid line at 100mm separation with the position of the monitor probe being changed. Below 200 MHz, the coupling values are very similar but they deviate significantly above this frequency.

If the experiment is repeated with the monitor probe at the high impedance end, the coupling for the two separations is similar with some slight shift of resonant frequency.

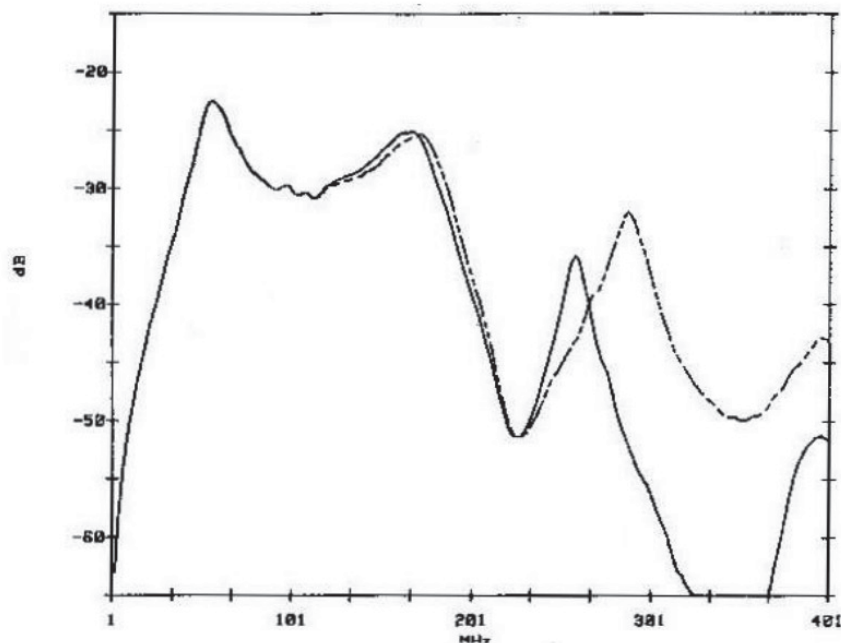


Figure 20.UG-21: Variation in Coupling by Monitor Probe Movement on a Single Wire

Figure 20.UG-22 shows the results of similar measurements made on the control bundle of the same Doppler navigation system as before. As can be seen, below 200 MHz, the coupling values are similar but vary by up to 10 dB above this frequency.

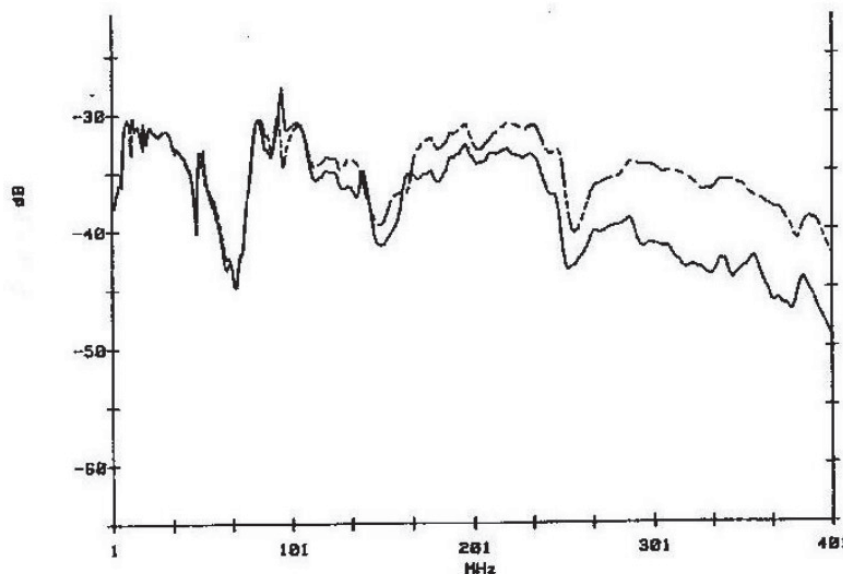


Figure 20.UG-22: Variation in Coupling by Monitor Probe Movement on a System Harness

From these and many other results from similar experiments, it is apparent that great care must be exercised in using the values of injected current obtained above 200 MHz and they should be only used as a guide when comparing them with the currents induced on the same cable bundles during aircraft EMC certification tests. Experience has shown that the errors caused by the variation in the position for either probe from that specified in the test method tend to be less for multi-wire bundles than for a single wire where the Q is likely to be higher. The injection probe helps to reduce the Q of the lines under test because of their high coupling capability.

Sometimes the noise in the cables under BCI testing is greater than the current level to be injected in the cables.

Use of broadband sensors (power meters or oscilloscopes) would cause the closed-loop control system to reduce the injected power in order to control the current on the cables at the requested level. This will cause an “under test” of the EUT. This condition can be identified by performing a measurement of the current on the cable using the broadband sensors before starting the test, checking that the measured current is not greater than the target injected current.

To avoid such a condition, one of the following strategies would be recommended:

1. Use of narrowband sensors (Spectrum Analyzer or Receiver), keeping the bandwidth as small as is possible but compatible with the Injected signal. This would limit the problem to specific frequencies or bands where the noise cable current is greater of

2. The wanted injected current. Those remaining frequencies with this issue should be addressed.
3. Over the frequency range where the broadband noise is greater than the current test level, increase the forward power level until the induced current exceeds the noise. The forward power should not exceed the forward power limit.

Note that use of a fixed forward power as obtained during the calibration phase, without monitoring the current, may over test the EUT and/or cause damage on the support units in cables with low impedances.

20.UG.5 Radiated Susceptibility (RS) Test - Anechoic Chamber Method

a. Applicability/Intent

The purpose of this test is to ensure that the EUT does not exhibit any degradation of performance or malfunction when illuminated with electro-magnetic fields of the specified electric field level.

The test consists of radiating the EUT and associated cable bundles by using field-generating antennas in a semi-anechoic room.

b. Radiated Field Calibration

The field at the location of the system to be tested is pre-calibrated prior to installation. A small isotropic field sensor is placed at the center of where the equipment under test will be located and the forward power to the transmitting antenna is adjusted until the required resultant field strength as measured by the probe is achieved. The forward power is recorded and this is the power used during the test.

Alternatively, where it is not practical to remove the system under test from the enclosure for the purpose of pre-calibration, the calibration may be performed at an alternative location within the same anechoic chamber with the system under test present. The calibration is to be performed with the field probe positioned in accordance with DO-160G over a similar ground plane, and with a similar absorber configuration. It is required that the calibration is not impacted by the presence of the system under test within the chamber. Since it is not possible to prescribe specific layout criteria which will ensure that the alternative calibration position would give the same power to field transfer function as pre-calibration in an empty chamber, for all scenarios below 1GHz, it is recommended that an additional check is carried out to confirm acceptable field generation. At frequencies above 1GHz it is likely that the directivity and relatively narrow beam width of the transmit antenna will result in an acceptable calibration which is not significantly impacted by the presence of the system under test. At lower frequencies the potential for impact, however, increases. An example of how a check may be achieved would be comparison with a pre-existing field calibration in the empty chamber. Considerations would include commonality of transmit antenna, antenna feed cable loss, forward power, monitored field, forward power/ field linearity and amplifier harmonic content. (Note: it should be established that the uncertainty budgets associated with field probes and Spectrum Analyzers, used in forward power measurement, are known and similar to avoid over or under test.) It is essential that the system under test is adequately illuminated over the volume of the test set-up. Where it is not possible to illuminate the system using a single transmit antenna position, multiple antenna placements are to be used. The number of antenna positions should be determined, using simple trigonometry, to ensure that all elements of the system under test are adequately exposed within the 3dB beam width of the transmit antenna. The radiated E-Field

calibration is performed using a CW un-modulated signal because typical diode-based E-Field Probes do not measure the true rms value of a modulated signal and would thus provide erroneous results. Thermocouple-based E-Field Probes do measure the true rms value and therefore could be used to measure the peak rms value of a SW or PM modulated E-Field provided that the signal duty cycle is known. Forward power is measured by means of a directional coupler feeding a suitable power measurement device.

As the fields required may be higher than the isotropic field sensor can withstand or measure accurately, the calibrated field strength at the location of the EUT can be determined by monitoring the increase in signal from the reference antenna above the level that could be measured by the isotropic probe and noting the forward power drive; the probe being removed at these higher levels. The reference antenna also provides a useful check that the required field is being generated during the test and that no malfunction of transmit antenna or feeder has occurred. This could also be achieved by monitoring the net power to the transmit antenna. It must be remembered that the reference antenna does not provide in its own right an absolute measurement of field strength at the location of the EUT. [Figure 20.UG-23](#) shows the test layout.

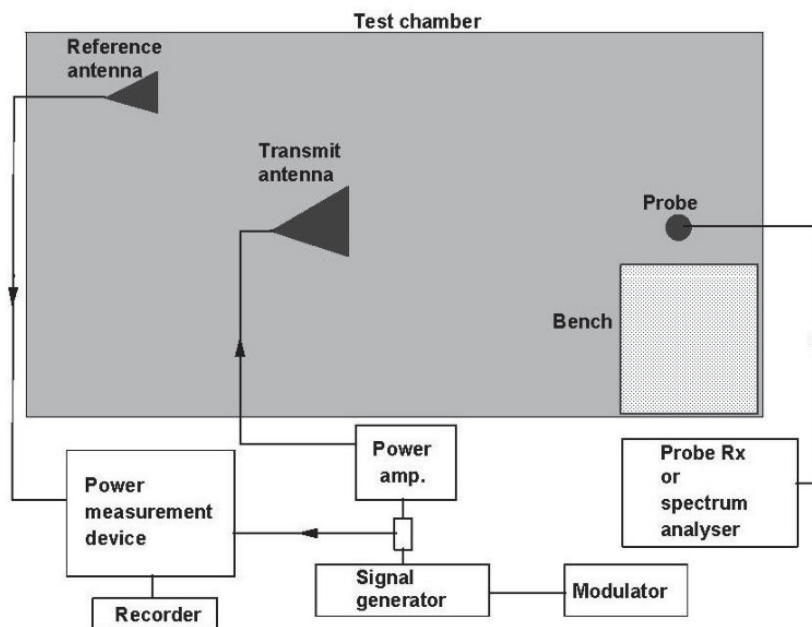


Figure 20.UG-23: Field Calibration Test Arrangement

c. RS Test Set-up

The EUT and associated cable harness at a particular frequency must fit into the half-power beam width of the receiving antenna. Typically, antenna datasheets will provide this information as a function of frequency and antenna polarity. Beam width is usually provided as the angle between the half-power points on either side of the antenna's primary lobe.

Beam width in degrees and the length of the test setup are incompatible measurements. The beam width of the antenna should be converted to a useable exposure length across the test setup. This is done by using right triangle trigonometry to determine the equivalent beam width as a linear length. [Figure 20.UG-24](#) depicts how the tangent

function can be used if the distance to EUT is known. The equation is provided to calculate the equivalent beam width length.

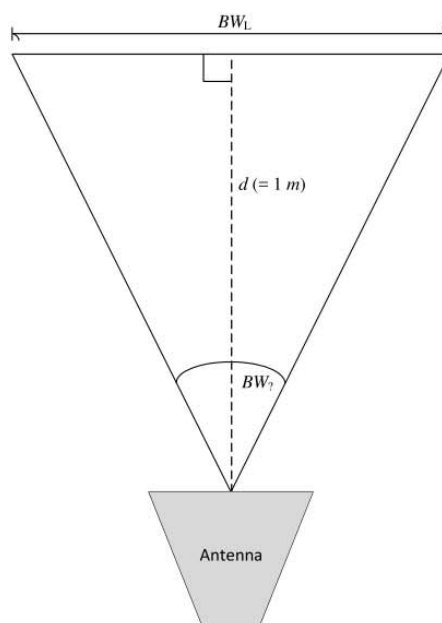


Figure 20.UG-24: Antenna Beam Width Diagram

$$BW_L = 2d \tan\left(\frac{BW_a}{2}\right)$$

With an equivalent beam width length determined as a function of frequency for each antenna, the required exposure width of the test setup must now be compared against it. This exposure length is the sum of the EUT width and a half-wavelength of cabling and/or power leads. Depending on the EUT's orientation, there could be considerable overlap between the EUT and cables therefore reducing the required exposure length. If the beam width length is less than the required exposure width, then multiple antenna positions are required.

The EUT and associated cabling may be setup in multiple ways. Two examples are shown in [Figure 20.UG-25](#) and [Figure 20.UG-26](#). [Figure 20.UG-25](#) shows all power lines and cabling routed on the same side, while [Figure 20.UG-26](#) shows the power lines routed in one direction and the I/O routed in the opposite direction. [Figure 20.UG-26](#) may require 2 antenna positions in order to ensure that $\lambda/2$ of the I/O cabling and then $\lambda/2$ of the power is exposed to the 3dB beam width of the antenna. This should be closely analyzed during the test procedure phase.

Note that in some cases the power lines may not have the full $\lambda/2$ exposure, ie, $\lambda/2$ at 100MHz (low end of RE and RS) equals 1.5m. If only 1.0m of power line is used, the $\lambda/2$ guidance in DO-160G is not met. However, this is acceptable and the power lines do not need to be lengthened.

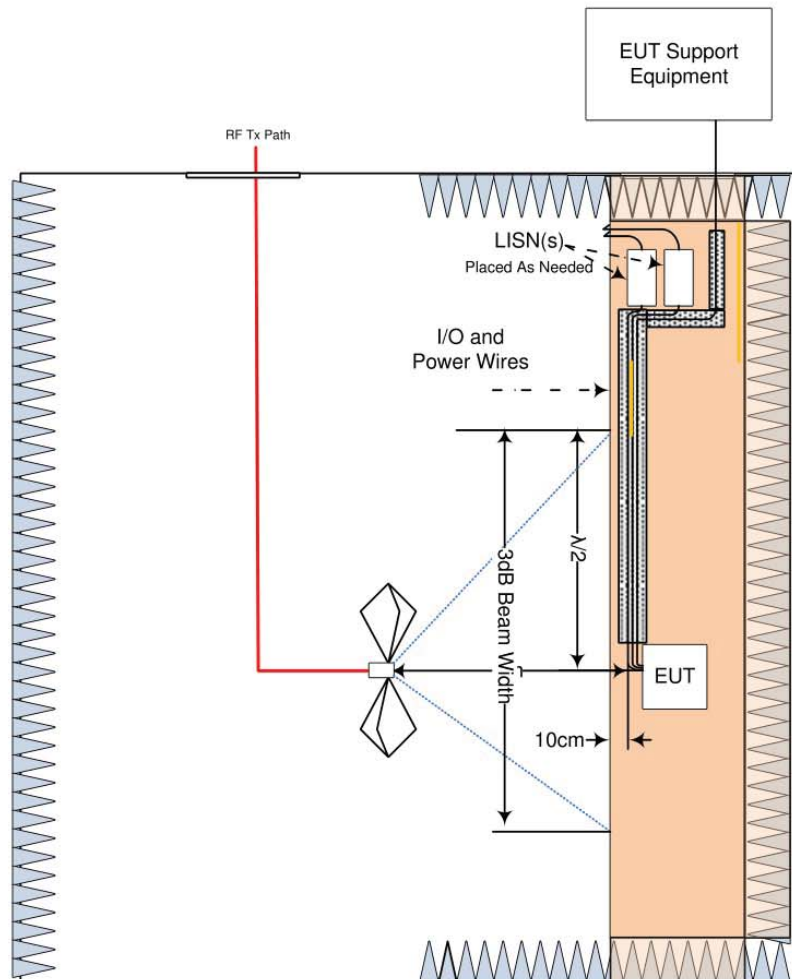


Figure 20.UG-25: Cables Routed in Same Direction

of the antenna, caused by coupling to the shielded room. These create significant problems for the driving amplifier to maintain the required field strength.

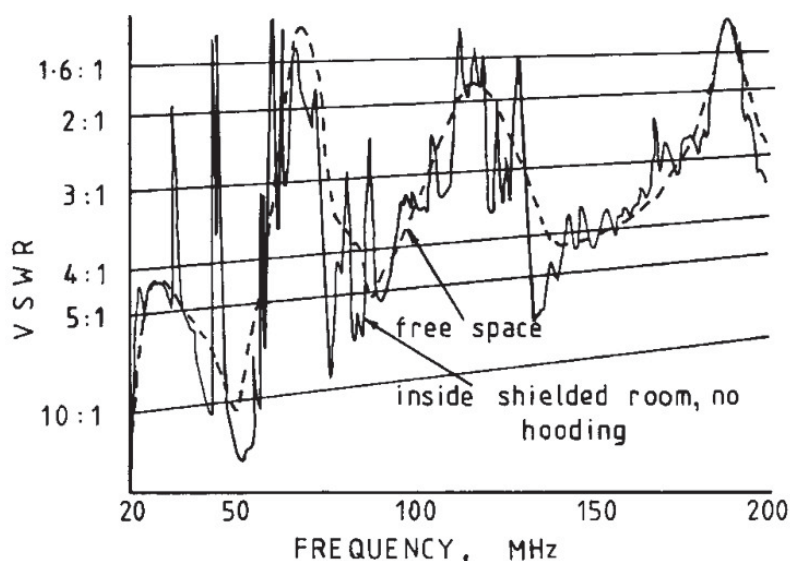


Figure 20.UG-27: Radiated Susceptibility Test - VSWR of the Biconical Antenna in a Shielded Room - No Anechoic Absorber in Close Proximity Around Transmitter

Figure 20.UG-28 shows the effect of placing anechoic absorber on three sides of the antenna at 0.75m distance with AN 79 anechoic lining and the resulting significant improvement.

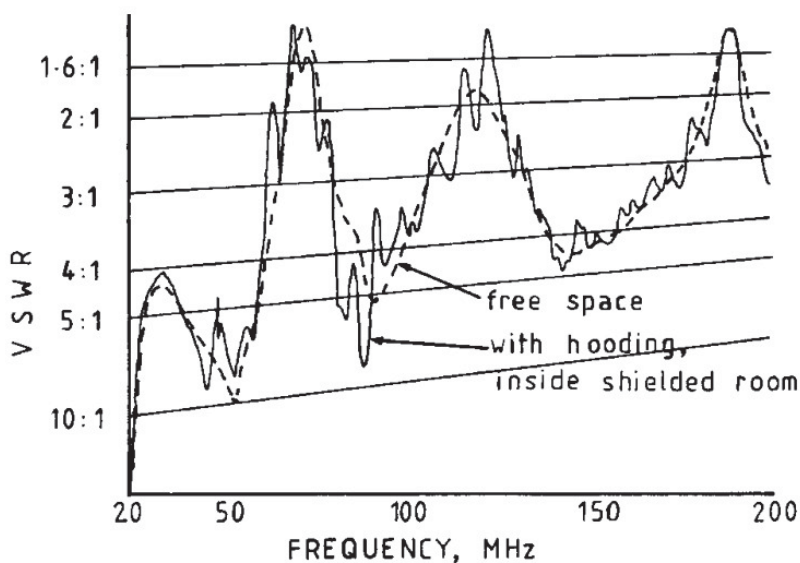


Figure 20.UG-28: Radiated Susceptibility Test - VSWR of the Biconical Antenna in a Shielded Room - With Anechoic absorber in close proximity around transmitter

The guidance and methods in section 20 shall be used for production and measurement of electric fields. The test arrangement is the same as for calibration apart from the addition of the system under test.

No point of the field-generating and field-measuring antennas should be less than 0.3 m away from any anechoic lining.

When aiming the antennas to establish the RF field strengths at the EUT, the antenna may be tilted in the vertical plane (for example when the EUT is small).

When the 3 dB beam width of the antenna does not cover the EUT, the antenna may be tilted in the vertical plane as a means of performing multiple area scans.

The power level established during the calibration should not be adjusted if tilting the antenna during the RS test. In any case, the EUT must be within the 3 dB beam width according to Section 20, paragraph 20.5 c). The tilt angle (when different than zero) should be recorded in the test plan or report.

d. RS Test Procedure

A definitive test requires that the EUT is illuminated for ‘worst case’ coupling. Section 20 is vague in its definition of equipment aspect angles to be irradiated:

The intent of this requirement is that any face that will not be directly exposed to the transmitting antenna should be justified by the equipment manufacturer, for example, in the test plan or procedure. In the determination of test aspect angles, it should be noted that at higher frequencies inadvertent apertures and discontinuities may result from the implementation of joints and seams. The publication “Some implication of a single aspect angle electromagnetic compatibility test” Gustav J .Freyer and Mats G. Bäckstrom provides illustration of what kind of error can be introduced by single aspect angle testing. In general, the EUT side with apertures for connectors provides significant coupling and should be included in the test. Display faces may also allow significant coupling and should also be tested. EUT sides whose apertures (e.g. seams) are smaller than those tested on some other side of the EUT could be justified for not testing. Effects of EUT-internal partitioning (screening) and aperture polarity may also be considered. The level of rigor in the justification should be commensurate with the EUT’s system criticality.

In terms of radiating the EUT with conventional radiated methods, two different manners have been used. The first method is to sweep or step the frequency range while maintaining the power output to the antenna. The second method is to stop illumination before stepping and then increase the power at next frequency up to the required level. These two methods may produce different results. The second method may be useful in detecting window effects. Such window effects are directly accounted for when using the reverberation chamber test procedure.

Window effect is the term for system susceptibility observed during immunity testing that occurs at a certain test level, but then apparently disappears at a higher level. An example of this is a system that utilizes a solid state switch and the upset is defined as inadvertent operation of the switch. As the level of applied RF is increased, a threshold level is reached where the controlling circuitry changes state, thus operating the switch. At higher levels, the controlling circuitry is saturated, thus no longer changing the state of the

switch. If, in this case, the test level was just applied at the higher level, then the susceptibility would not have been found. Equipment should be reviewed for circuits which may exhibit window effects to determine the system response and necessity to conduct window effect test.

According to the HIRF User guide, if checking for window effect is intended, the signal source should be programmed to reduce its output by 12 dB at a minimum of 5 frequencies per decade, logarithmically spaced. At these frequencies, the output is then stepped from full amplitude to 6 dB down and then to 12 dB down and increased in the same manner to the pass/fail level. If it is intended to sweep across the frequency band at the test level, to reduce test time it should be demonstrated that window effect is not applicable to the system under test.

Specific tests for window effects need not be done for Reverberation Chamber tests as the field intensities are constantly changing and exercising the system under test over the full frequency range.

e. RS Modulations

It is acceptable to apply the different modulations in any order desired. This may be desirable at some laboratories to optimize testing. E.g., it is acceptable practice to go to a frequency, apply the CW field and dwell. When CW is completed, turn on the modulation from the signal source; apply the SW field, dwell, and then change frequency.

The intent is that each frequency is tested at appropriate field strength and modulation. The order of frequency or modulation is not considered relevant to the test.

20.UG.6 Radiated Susceptibility (RS) Test; Reverberation Chamber - Method

20. UG.6.1 Applicability/Intent

The increasing levels of the electromagnetic environment have meant that across a wide range of EMC Standards, test levels have been increasing. The result is that test facilities have had to invest in more expensive test equipment with the resulting increase in test costs. In some instances equipment test levels have been set at a few kV/m pulsed. At these levels standard procedures become impractical especially when dealing with large equipment.

For many years, research on the use of reverberation chambers for EM vulnerability testing has been undertaken in many countries, especially the US, Italy and the UK. With the increasing demand for higher levels, the reverberation chamber has come to the front as the most efficient technique, in terms of required power, to deliver high fields. As a result the technique was incorporated into DO-160 at revision D.

20. UG.6.2 Procedure Overview

A reverberation chamber (Figure 20.UG-29) is a shielded enclosure with the smallest dimension being large with respect to the wavelength at the lowest useable frequency. The chamber is normally equipped with a mechanical tuning/stirring device whose dimensions are significant fractions both of the chamber dimensions and of the wavelength at the lowest useable frequency. When the chamber is excited with RF energy the resulting multi-mode electromagnetic environment can be “stirred” by the mechanical tuner/stirrer. The resulting environment is both isotropic and uniform when averaged over a sufficient number of positions of the mechanical tuner/stirrer.

RF is transmitted into the room via an antenna, beamed preferably at the paddle wheel or, if more practical, into a corner. Design details of the reverberation chamber can be found in the National Institute of Standards and Technology report 1092.

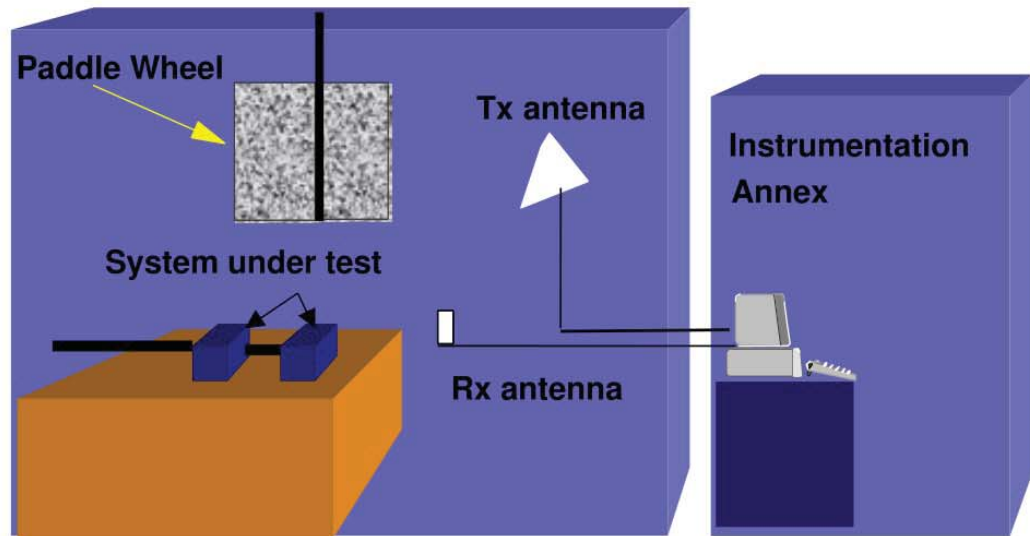


Figure 20.UG-29: Side View of a Typical Reverberation Chamber

As the paddle wheel rotates, the maximum field obtained during one rotation of the paddle wheel is the same at any point within the calibrated working volume.

The chamber is normally used at frequencies above that which supports 60 modes. The equation below defines the frequencies for the various modes that exist in a chamber of dimensions $a * b * d$.

$$f_{mnp} = 150 \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{p}{d}\right)^2} \text{ MHz}$$

where m, n & p are integers

Depending on the size of the chamber, field strengths of the order of 10-100V/m for 1Watt net input power to the chamber can be achieved in the microwave frequency band. The lower the chamber losses the higher the field strength obtained.

Recommendations are provided below that could help building a reverberation chamber suitable for section 20 testing:

- Experience has shown that the paddle wheel or tuner provides better stirring performance with a diameter of at least half a wavelength at its lowest frequency of operation. The paddle wheel diameter and height should be at least one-half wavelength at the lowest useable frequency. The larger the paddle wheel, the better the performance of the reverberation chamber, particularly at lower frequencies. If the enclosure configuration permits, a paddle wheel with a minimum dimension of one wavelength (at the lowest useable frequency) should be a design goal. The paddle wheel should have one dimension a significant fraction of one dimension of the room. The recommendations in the IEC

- Reverberation chamber test technique is $\frac{3}{4}$. The paddle wheel should be asymmetrically shaped. It is usually most convenient to support it from the ceiling with the driver motor outside the chamber. A computer controlled stepping motor is desirable.
- At least 60 modes should exist at the lowest frequency of use.
- The chamber should be free of any materials, which exhibit absorptive properties. Examples of articles, which should be removed, include tables, chairs, floors, etc., made of wood or other absorbing materials.

In addition various papers in the USA have indicated that during one rotation of the paddle wheel the ratio of the peak field strength to the average at a fixed location in the room should lie between 7-8 dB. The histogram (Figure 20.UG-30) shows this ratio for various frequencies in a large reverberation chamber, which meets all the above operating criteria down to 90 MHz:

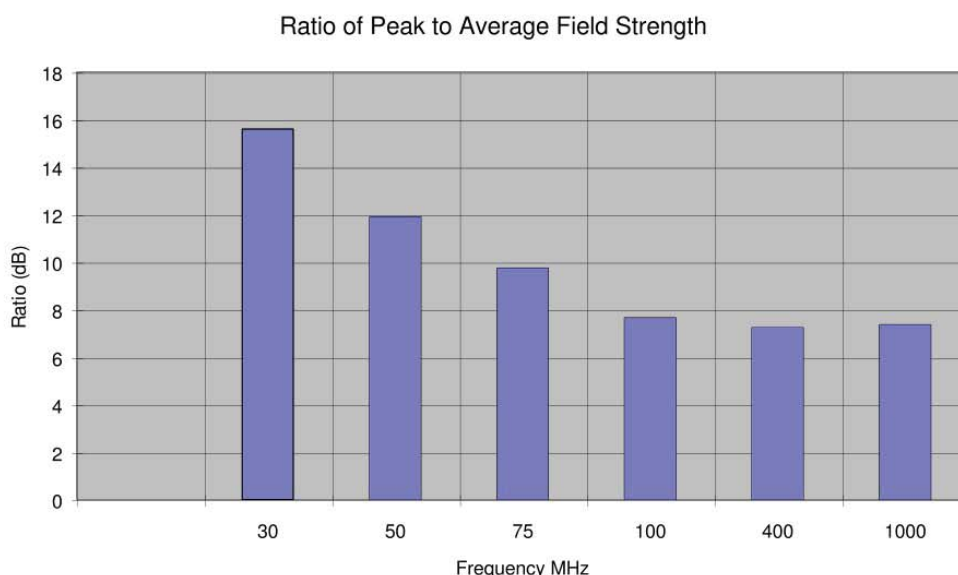


Figure 20.UG-30: Histogram Showing an Example of the Ratio of Peak to Average Values of Field Strength

As can be seen from the histogram, the ratio exceeds 8 dB at frequencies below the minimum at which the room meets the criteria defined above.

Reverberation chamber tests may be advantageously used in place of anechoic chamber method for radiated susceptibility testing at frequencies greater than 100 MHz. (Note the chamber size will determine the lowest useable frequency for a particular facility). A reverberation chamber test generates a complex electromagnetic environment similar to that in an aircraft compartment although an aircraft compartment is generally more heavily loaded resonant cavity than a reverberation chamber.

The advantages of a reverberation chamber are:

- (1) It illuminates the entire working volume inside the chamber rather than "spot" illumination of a limited volume. (The desired field levels existing in only part of the volume for any tuner position, but are uniformly distributed throughout the tuner cycle);

- (2) Multiple configurations are not necessary since the mechanical stirrer moves the fields through all angles and polarizations throughout the chamber;
- (3) Generally, less RF input power is required to generate a given test field due to the high Q of the reverberation chamber than is required in an anechoic chamber. However, it is possible to use very high gain antennas for anechoic chamber tests which give a similar field strength to the reverberation chamber, albeit with a relatively small illumination area. The small illumination area, relative to the EUT size, may necessitate multiple area scans.

The limitations of a reverberation chamber are:

- (1) That the mode density at frequencies below a calculable limit based on chamber size is too low to provide adequate mode mixing and hence randomized test fields;
- (2) For light loading conditions, the time constant of a reverberation chamber may be too slow for tests requiring fast rise time waveforms;
- (3) The directivity characteristics of antennas or EUT's are not preserved, which may limit the possibility for investigating coupling path in case of test failure. However, investigation is not the purpose of section 20 procedures.

The thoroughness of exposure in a reverberation chamber is difficult to achieve in practice with any other test method. The time required for testing an EUT depends on the response time of the EUT, as in other methods.

The EUT and test equipment response time should be considered to verify that the stirring speed insures that the field evolution is slow enough to detect susceptibilities. This verification should be documented as well in the test report. Dwell times associated with anechoic test methods may be applied when choosing to stop the stirrer.

Field stability may be a key issue for test homogeneity (as function of frequency), reliability (as function of EUT response time), repeatability (as function of Chamber and paddle wheel size). One proposal is provided below on how to define the lower frequency above which the standard procedure may be customized:

Rotate the tuner according to Section 20.6.2.c.ii. For a given test facility, the duration where the field strength may remain above -3dB of the maximum value around the max field peak will depend on the frequency. Slowing the tuner speed or stopping it at a number of positions may be required at higher frequencies when the instability of the field due to stirrer rotation may not give time for the EUT and/or associated monitoring equipment to react. Defining the frequency above which such improvement of the procedure needs to be considered will require definition of the EUT and/or monitoring equipment response time and correlation with the histogram of the field in the room for a tuner rotation. An example of such a histogram and how to use it is provided in [Figure 20.UG-31](#).

The basic procedure is particularly adapted to fast reaction equipment. If stopping is chosen, then the number of positions will be 12 as a minimum and may be increased to achieve higher levels as described in 20.6.3.1.

Using the field variation plot as function of the tuner position, as illustrated above, it is possible to determine the angular variation tolerance necessary for the field strength to remain within 3 dB of the average field strength met at one stirrer position. It is then possible to verify that the oscillation resulting from the stopping of the stirrer will not exceed this angular tolerance, which will allow stirring and stopping the stirrer during the test without waiting for any stabilization time.

As a function of equipment reaction and monitoring characteristics, and depending on the reverberation chamber size, test frequency range and number of modulations, the procedure of DO-160G may take longer than the one of DO-160F if slowing down or stopping the stirrer is applied.

Some thought has been given to defining a mode stirring procedure that would allow for multiple test frequencies within one tuner rotation at slower speed. Such a procedure would enable reasonable field stability without stopping the tuner rotation and without resulting in excessive test duration. The committee has not considered this procedure mature enough, in terms of supporting data, to be introduced in this issue of the document.

Issue E and F of DO-160 section 20 were using mode tuning. The rationale for exclusion of continuous rotation of the paddle wheel/tuner during testing was first the inability to define the rotation speed to ensure adequate “dwell time” of the RF field over the EUT and second the inability for the field probe to measure during the stirrer rotation. Issue G of section 20, based on experience gained, has been able to provide an acceptable answer to these concerns.

The procedure is split into several phases:

a. Prior to the Fitting of the Test Bench and/or EUT

A performance based field uniformity calibration technique should be performed to demonstrate adequate reverberation chamber performance following initial construction or after major modification to the reverberation chamber. The chamber calibration technique is carried out to demonstrate the chamber meets the field uniformity requirements. In addition, it is important to determine the lowest useable frequency (LUF) of the reverberation chamber employed.

During the EUT test, the electric field strength in the chamber is determined from the received power (P_{rcvmax}) on a monitoring antenna (with 100% efficiency) from the equation:

$$E_{meas} = \sqrt{\frac{377 * 8 * \pi * (P_{rcvmax})}{\lambda^2}}$$

Although this equation has been validated it is recommended to verify that the test chamber is indeed working well before the test is run. The receive antenna as used in Section 20.6.3.1 should be placed in the test volume. Using the results of the received power on the antenna and the E field probes measurement performed in Section 20.6.3.1, the equation which provides the relation between the maximum field strength inside the

chamber (V/m) and the maximum recorded power measured over one paddle rotation (W) used in 20.6.2.2 c) can be validated.

Note in 20.6.2.2 k) indicates that slowing down tuner speed or stopping it at a number of positions may be appropriate at higher frequencies when the instability of the field due to stirrer rotation may not give time for the EUT and/or associated monitoring equipment to react.

For a given test facility and tuner speed, the duration where the fields strength will remain above -3dB of the maximum value around the max field peak will be depending on the frequency.

In order to be able to do it in the best efficient way, the field evolution in the chamber should be identified at the lowest usable frequency and few higher intermediate frequencies.

An example of the chamber field histogram is provided in the [Figure 20.UG-31](#).

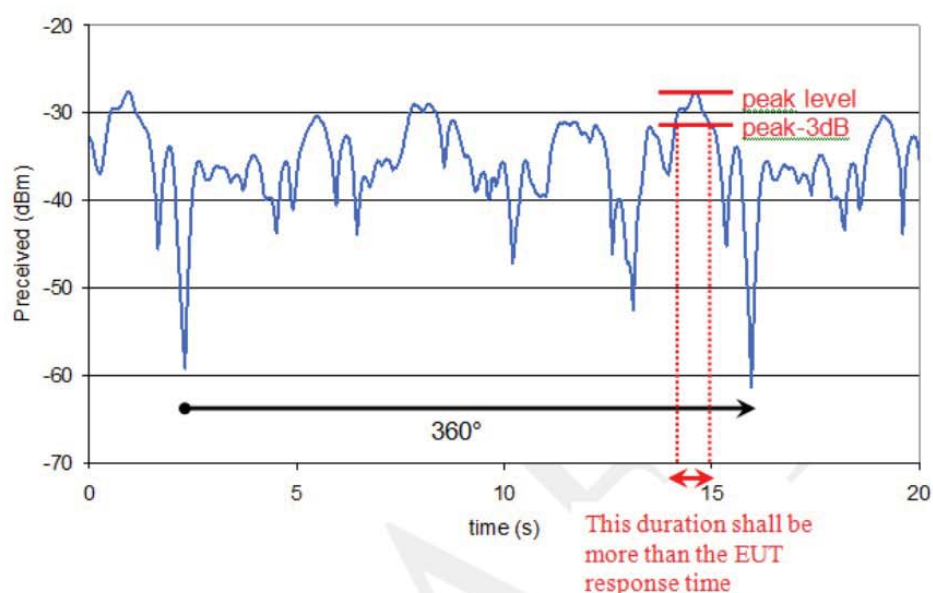


Figure 20.UG-31: Field Variation with Respect to Tuner Rotation

b. The EUT Test

For a given frequency range, the stirrer max speed should be chosen such that the duration of the peak field within 3dB is greater or equal than the EUT and monitoring equipment response time. For a given installation the evolution of the peak width is linear with frequency therefore the estimate of the max speed per frequency range is easy and quick based on the histogram of the field at the Lower usable frequency. This estimate can be then verified with the histograms plotted for the few higher intermediate frequencies.

Stopping the tuner may be chosen to assess equipment response in a time-invariant field. The amplitude is not necessarily that of the defined test level. Stopping the tuner provides additional time to monitor the performance of the unit.

As shown in the field variation plot as function of the tuner position, illustrated in [Figure 20.UG-31](#), around a particular position providing high field strengths, the tuner settling

movement from stopping the tuner will not significantly influence the field level. This will allow stirring and stopping the stirrer during the test without waiting for any stabilization time.

Since the receive antenna will represent only one position within the working volume, the P_{rcvmax} value variation could be excessive and cause an unnecessary penalty on forward power requirements during a test.

As shown in Figure 20.UG-32, the P_{rcvmax} data is demonstrated to be repeatable for three independent data sets at one receive antenna location yet still demonstrate frequency to frequency amplitude variation.

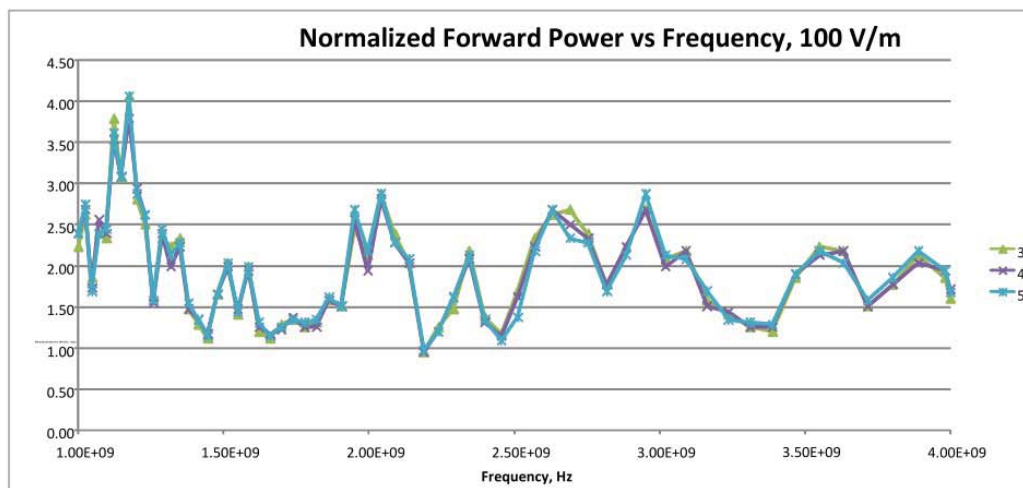


Figure 20.UG-32: Forward Power Repeatability, 3 Independent Runs, One Antenna Position

Frequency point to frequency point amplitude variation of 3 dB or greater can cause test equipment control problems with frequency synthesizer internal step attenuators, frequency synthesizer power output leveling loops or software forward power control algorithms.

One method to mitigate the effects of the data scatter is to use a curve fitting algorithm on the data set. In previous versions of section 20 reverberation testing, curve fitting techniques have been used on the CLF data as permitted by a Note within the section to mitigate the frequency to frequency variation. The intention of the User Guide was to remove the Notes within the body of the section 20 and move the Notes to the User Guide. The previous note allowed averaging the data sets to be compared over 4 frequencies each side of the frequency being evaluated. There are other acceptable curve fitting techniques which can be used to evaluate the data such as; linear, polynomial, etc.

The scatter plot shown in Figure 20.UG-33 is normalized P_{rcvmax} values adjusted to a normalized 100 V/m field strength (E_{max}) using the equation listed in DO-160G Section 20 paragraph 20.6.2.b.iii;

$$E_{max} = \sqrt{\frac{377 \cdot 8 \cdot \pi \cdot (P_{rcvmax})}{\lambda^2}}$$

An example of using a rolling average curve fit routine is shown in Figure 20.UG-33. The moving average values can be the basis of determining the P_{target} value for an E_{desire} during the test.

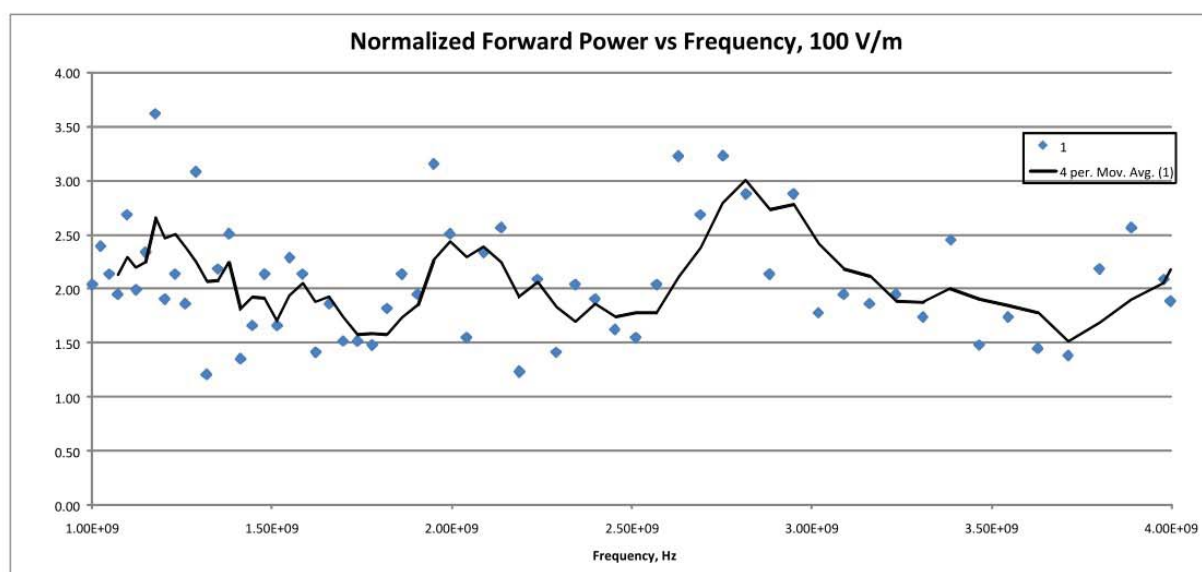


Figure 20.UG-33: Moving Average Technique on Measured Forward Power Data for 100 V/m Field Strength

Note: The moving average trend line used the following equation;

$$F_t = \frac{A_t + A_{t-1} + \dots + A_{t-n+1}}{n}$$

20.UG.6.3 Calibration, Chamber Field Uniformity and Loading Validation

20.UG.6.3.1 Field Uniformity Validation

Independent Samples in One Paddle Wheel Rotation

The number of tuner positions to be used during the test is the number used during calibration to provide the required field uniformity providing more than 12 steps are used. Increasing the number of steps improves the uniformity and increases the probability of reaching the maximum field level for a given power into the chamber. The most important point for achieving the homogeneity requirements is to work with a uniform angular distribution of the test samples and to consider a sufficient number of samples. Experience has shown that working with more samples than the minimum number estimated with the “independence rule” gives a better result providing they are uniformly distributed. However, increasing the number of steps increases the test time. Each step should provide an “independent sample”; reducing the step size would not improve the results of field uniformity validation. This means the field distribution has to change enough between the steps to provide a statistically independent sample. The ability to provide a large number of steps giving independent samples during the tuner rotation is a measure of the effectiveness of the tuner. If inadequate number of samples can be achieved then the design of the paddle wheel in terms of size and shape needs to be changed.

To determine the step size required to provide independent data samples at each step, the correlation coefficient needs to be determined. When the correlation coefficient between paddle wheel step sizes falls below 0.36, then the data is considered to be an independent sample.

The paddle wheel performance data is obtained by monitoring the received power at evenly spaced intervals over one paddle wheel rotation (Note: the number of points per rotation determines the resolution of the correlation calculation). The paddle wheel performance is evaluated by calculating the correlation coefficient between the data obtained to that of the original data that has been shifted one sample and the last data point moved into the first position as shown below (450 samples assumed).

D1, D2, D3, D4, D5, D6, D450
 D450, D1, D2, D3, D4, D5, D6, D449
 D449, D450, D1, D2, D3, D4, D5, D6, D448
 D448, D449, D450, D1, D2, D3, D4, D5, D6, D447

The correlation coefficient can also be calculated using the following formula:

$$r = \frac{\frac{1}{N} \sum_i^N (x_i - u_x)(y_i - u_y)}{\sqrt{\left(\frac{\sum_i^N (x_i - u_x)^2}{N} \right) \left(\frac{\sum_j^N (y_j - u_y)^2}{N} \right)}}$$

$\uparrow$
 σ_x^2

$\uparrow$
 σ_y^2

Note: x_i & y_i are received power values

y_i is the same distribution as x_i but shifted by M samples (in this case tuner positions)

u_i is the mean of the original received power vs tuner position

Since the y distribution is the same as the x distribution except for the notation of tuner position:

$$u_y = u_x \text{ and } \sigma_x = \sigma_y$$

The correlation coefficient can be obtained using the correlation function built into most spreadsheets by comparing the original data set to the shifted data sets. An operational definition is that the data becomes uncorrelated when the magnitude of the correlation coefficient is less than 0.36 (e^{-1}). Dividing the total number of samples (e.g. 450 above) by the number of steps necessary to reduce the correlation coefficient to less than 0.36 yields an estimate of the number of independent samples the tuner can provide at a particular frequency.

Example: Carry out the above procedure on a chamber rotating the mechanical tuner 360 degrees in 450 evenly spaced steps at 80, 100 and 500 MHz. If the correlation coefficient became less than 0.36 after 25, 15, and 5 steps of the tuner respectively, then the tuner could be expected to deliver 18 independent samples at 80MHz, 30 independent samples at 100 MHz, and 90 independent samples at 500 MHz. As shown in the next section, the number of tuner steps required may exceed the ability of a single tuner to provide. In such cases a second tuner will be necessary.

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DO-160G

**Environmental Conditions and Test Procedures
for Airborne Equipment**

User Guide for Section 21

Emission of Radio Frequency Energy

**Based on
DO-160G Section 21**

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21.UG.0 Emission of Radio Frequency Energy**21.UG.1 Purpose of the User Guide**

The purpose and scope of this Users Guide is to provide additional information and clarification on the test procedures for section 21. However it is still highly recommended that detailed discussion will take place between the aircraft and the equipment manufacturer before running the test.

The purpose of testing within Section 21 is to ensure that equipment will not emit undesired noise in excess of the specified levels. These emissions may be conducted on wires between connected EUTs or may be radiated from one cable to another cable or EUT. These emissions may also be radiated from the EUT.

Two sets of measurements are performed; one addressing the conducted emission of the wiring by means of measurement probes, and the other addressing the radiated emission of the equipment and associated wiring by means of a receiving antenna

21.UG.2 Equipment Categories

Categories are defined in terms of location and separation between the equipment and aircraft radio antennas. As these parameters are widely linked to aircraft type and size, some examples are given with each category definition.

Category B**Category L****Category M****Category H****Category P****GPS/GNSS / HF Receiver Limits**

There have been recent developments in the application of GPS/GNSS receivers for aircraft landing operation. As a consequence the correct functioning of this equipment is becoming more critical and it has been considered a need to decrease the emissions of the

avionics in the GPS/GNSS frequency range. A new requirement has been introduced in the new Category P curve limit of DO-160G Section 21 to anticipate this issue.

The Category P conducted levels were also adjusted to address issues with HF receivers onboard the aircraft.

Category Q

Back Door versus Front Door Coupling

Front door coupling can be described as in-band emissions emanating from a source on the aircraft to the receive antenna of other equipment on board the aircraft. Front door coupling refers only to aircraft radio receivers.

Back door coupling can be described as emissions radiated from a source directly to other equipment on board the aircraft via radiated via apertures, conducted directly by wiring, or radiated by wiring.

In-band emissions are emissions that are within the receiver pass-band of the victim. This assumes that the victim is an intentional receiver of EM fields, such as through an antenna.

21.UG.3

General Requirements

Bonding of Ground Plane

(Refer to DO-160G, Section 20.3.a (1))

For the bonding of the ground plane to the anechoic shielded enclosure, it is suggested that bond straps be routed horizontally to the wall. It is suggested that bond straps have a maximum length to width ratio of 5 to 1.

(Refer to DO-160G, Figure 21-6, Note 3, Figure 21-11, and Note 3)

Height of Test Table

The height of the test table is not defined in DO-160G. Nevertheless this plays a role in regarding the comparability of measurement results between laboratories. In order to reduce variability between test sites a height of 35.5" (90cm) is suggested.

Front End Overload during Emissions Testing

Care should be taken to ensure that the signals applied to the front end of the measurement equipment do not cause front end overloading. EMI receivers or spectrum analyzers with a pre-selector are typically less sensitive to front end overload.

It is important that all cables used in the measurement set-up represent the aircraft installation as closely as possible regarding types and connectors. It is recommended that as much information as is available, regarding the test setup be included in the test report. This helps to ensure that the test result applicability can be assessed as per paragraph 2.9 with minimum risk of retesting.

Measurement Times and Bandwidths

Dwell times should be long enough to ensure that a worst-case emission of the EUT is measured.

As a general rule, the worst-case emissions should be captured and therefore the dwell time should be set to cover the full operation cycle. During development of the test procedure, and in order to cover the worst-case emission, a thorough analysis of the EUT behavior may be carried out prior to the measurements. This analysis may include preliminary measurements using a spectrum analyzer and/or an oscilloscope. It may yield information about the expected nature of the emission (broad band, narrow band, intermittent, continuous). Some EUTs show not only continuous operation cycles in the millisecond range, but also software-driven intermittent emission behaviors. Operation cycles of a few seconds may occur for some EUTs.

21.UG.4

Conducted RF Emissions

Radiated emissions procedures in documented in DO-160 revisions prior to Revision F have included radiated RF Emissions measurements from 2MHz to 100MHz.

Beginning with Rev. F of DO-160, radiated emissions below 100 MHz were removed.

The following paragraphs relate the reasoning behind this change.

The main source of emissions below 100 MHz is from the cable bundle. Therefore it is more effective to measure these emissions by means of a conducted test rather than by a radiated emission test where the antenna is in its near field.

This is particularly true of the rod antennas used below 25 MHz. The main coupling mechanism for the rod antenna is capacitive in nature and varies considerably with small changes in distance or the geometry of the chamber, ground plane, etc. This leads to large deviations in measurements from one test lab to another.

In addition, there are few aircraft receivers in the frequencies from 30 to 100 MHz with the exception of marker beacon receivers at 75 MHz. Marker Beacon receivers typically have very low sensitivities and are relatively immune to emissions from equipment on board the aircraft.

In order to adequately evaluate emissions from 30 to 100 MHz it was decided to extend the conducted test method to 152 MHz. This provides an overlap with the radiated testing from 100 to 152 MHz where the conducted measurements begin to suffer from transmission line effects and where the shielded chamber performance begins to degrade below approximately 200 MHz due to the lower frequency limit of the absorber.

The change in radiated emissions limits allowed the introduction of the reverb chamber as a means to measure radiated emissions.

Common / Differential Mode Currents

In DO-160G it is not clearly stated, how power lines should be measured.

If the exact aircraft installation is not known, it is suggested that power lines be tested together as well as each individual power wire separately. For systems using AC and DC power, this may require that 8 power line measurements are needed (e.g. +28V, power returns longer than 1 meter, AC phase 1, AC phase 2, AC phase 3 and AC neutral plus the two bundles containing all of the power lines).

Cable Types

Cable Configuration(s)

In installations where a short grounding wire runs from the connector back shell to the airframe, care must be taken that the emission measurement is taken behind the grounding wire (see [Figure 21.UG-1](#)).

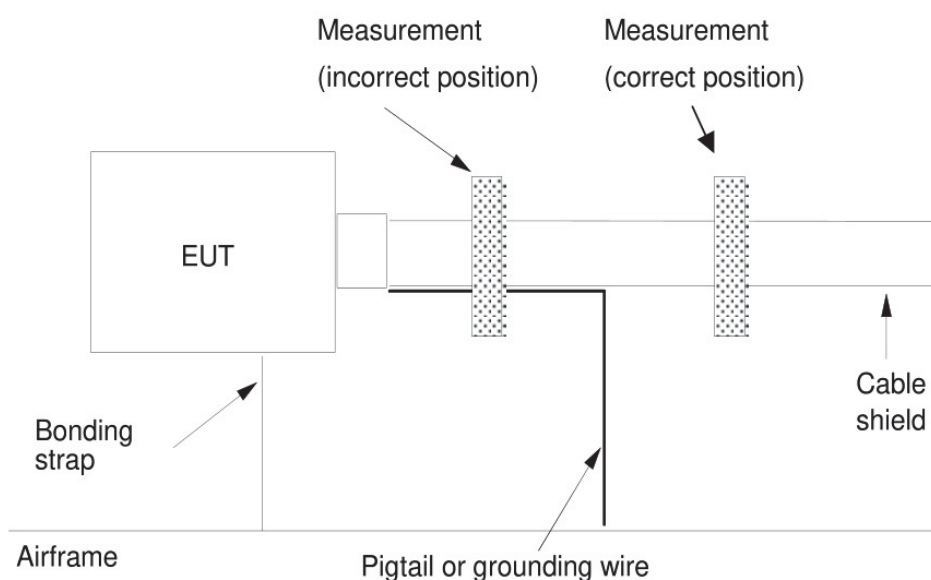


Figure 21.UG-1 - Problem caused by pigtail or grounding wire

If this is not taken into account, interference currents on the shield termination may cause inaccuracies in the measurement results. (Reference: RTCA DO-160G, Section 20.4.a, paragraph 3).

21.UG.5 Radiated RF Emission

Preliminary Emission Measurements

Measurements using different EUT orientations may be made to get some information about critical frequency ranges as well as the radiation pattern of the EUT. Measurements

using an oscilloscope may reveal a pulsing behavior of the EUT emission. These are helpful to determine operation cycles of the equipment and variations in amplitude of disturbances, which are needed to choose the correct dwell time. Based on these measurements, a list of frequency ranges, EUT orientation and dwell time should be created to produce maximum emission.

Factors Affecting Test Repeatability

Antenna Symmetry

With balanced antennas, e.g. biconical or log-periodic antennas (not to include horn antennas), the unbalanced coaxial cable should be adapted to the balanced antenna by means of a *balun* (Balanced - Unbalanced). If this conversion is insufficient, particularly during vertical antenna polarization, common mode disturbances on the vertical part of the coaxial cable can be observed. This may lead to substantial measurement errors. The following is a procedure for executing a symmetry check. This can be used to improve measurement accuracy. Symmetry checks may be carried out during antenna calibrations.

Balun DM/CM Conversion Check

The following method describes the measurement of two voltages, V_1 and V_2 in the frequency range for which the receiving antenna is to be used. The ratio of these voltages, both expressed in identical units (e.g., dB μ V), is a measure for the DM/CM conversion.

1. Set the receiving antenna under test vertically polarized with its centre at a height of 1.2m above the ground plane (floor of the shielded anechoic room). Lay the cable horizontally for $1.2\text{m} \pm 0.1\text{m}$ behind the rear active element of the antenna and then drop it vertically by a height of at least 1.2m to the ground plane.
2. Place a second (transmitting) antenna vertically polarized at a horizontal distance of 1m from the centre of the antenna under test with its tip 0.1m from the ground plane. The specification of the transmitting antenna shall include the frequency range of the antenna under test.
3. Connect the transmitting antenna to a signal source, for example, a tracking generator, set the level of that generator in such a way that, over the frequency range of interest, the signal-to-ambient noise at the receiver is larger than 10dB.
4. Record the voltage V_1 at the receiver over the frequency range of interest.
5. Invert the receiving antenna (rotate that antenna through 180°) without changing anything else in the set-up, in particular the receiving antenna cable, and without changing the setting of the signal source.
6. Record the voltage V_2 at the receiver over the frequency range.
7. The DM/CM conversion is sufficiently low if $(20 \log (V_1/V_2)) < 1\text{dB}$.

21.UG.6 Radiated RF Emissions; Reverberation Chamber Procedure**21.UG.6.1 Reverberation Chamber Requirements****21.UG.6.2 Reverberation Chamber Insertion Loss**

In this procedure a signal generator is set up to sweep 100 times during the rotation of the paddlewheel. This methodology was developed to allow any signal generator to be used with any spectrum analyzer. The offset of sweep times was required to ensure the signal generator and spectrum analyzer sweeps did not become synchronized and remain perpetually out of phase (i.e., the spectrum analyzer never records the signal the signal generator is inserting due to timing offsets).

21.UG.6.3 Radiated RF Emissions Test

During the development of the reverb technique it was noted that the limit lines originally incorporated into Section 21 were based on the directivity of a dipole. This led the working group to conclude that the assumption in Note 1 was in keeping with the original limit lines.

DO-160G

**Environmental Conditions and Test Procedures
for Airborne Equipment**

User Guide for Section 22

Lightning Inducted Transient Susceptibility

**Based on
DO-160G Section 22**

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22.UG.0 Lightning Induced Transient Susceptibility

22.UG.1 Purpose of the Test

This section of DO-160G is intended to provide test procedures and test levels that can be used to test equipment for indirect effects of lightning. It is the responsibility of the installer to make sure the test results satisfy the certification requirements of the proposed installation. This User guide does not contain requirements; it is intended to provide background information and considerations that improve the likelihood of successful test results.

22.UG.2 Definitions

Cable Bundles

Generally an interconnect bundle to be tested is associated with one connector. Grouping multiple connector bundles together during the test may not induce the appropriate current in the individual connector bundle.

Local Ground

For the purposes of DO-160G Section 20, 21 and 22 testing, a local ground is defined as a ground wire less than 1 meter in length. In actual installations there may be many exceptions to this rule. EUTs may be grounded locally but the ground wire may exceed 1 meter. As the length of the ground wire increases, the likelihood of lightning energy coupling onto that wire increases. If it is anticipated that the ground wires in the installed configuration will exceed 1 meter, testing of that wire should be considered. However as specified in the requirements, if the wire is not known to be run with the normal interconnect bundle for its entire length, it should not be included along with the bundle during test and should be tested separately.

Low Impedance Shielded Cable Bundle

A low impedance shielded cable bundle may have any or all of the following characteristics: the bundle is physically short, routed close to the ground plane, contains well-terminated shields (such as with 360 degree shield termination or very short pigtail termination wires), and has well-bonded connectors and equipment mating surfaces. This definition is only pertinent to the application of Waveform 6 as the multiple burst cable bundle test waveform.

22.UG.3 Categories

There is no requirement that pin injection and cable bundle test levels are identical. There is also no requirement that the single/multiple stroke test level and multiple burst test level are identical.

Separate designations for pin, single/multiple stroke and multiple burst allow for the selection of the maximum level desired in each category, which may allow the EUT to be installed in more applications.

The use of category Z does not mean that the EUT has not met the requirements of a particular category or that the test was unacceptable. Category Z means that the installer should look at the Environmental Qualification Form and/or Environmental Qualification

Report for additional test data. The use of Category Z may be acceptable to the installer after reviewing the actual test data.

22.UG.3.1 Waveform Set Designators (First and Third and Fifth Characters)

22.UG.3.2 Test Level Designators (Second, Fourth and Sixth Characters)

22.UG.4 General Test Requirements

a. Equipment Under Test

(1) Ground Plane

(2) Shock and Vibration Isolators

(3) Electrical Bonding

Bonding the EUT to a copper or aluminum table may be considered an “ideal” bonding arrangement. In one installation the EUT may be installed in a rack and in another, installed in a panel.

(4) External Ground Terminal

(5) Interconnecting Wiring/Cable Bundles

When very large and heavy injection transformers are required to perform the cable induction test, it may not be practical to place the injection transformer on the ground plane. In this situation, the injection transformer should be positioned such that the length of cable that is not kept above the ground plane is as short as practical, with the minimum amount of cable routed through the injection transformer. In this case, it may not be practical to maintain the proper distance from the injection transformer to the monitor probe; however, the monitor probe must be maintained at the proper distance from the connector backshell. Also, the shape and amplitude of the waveform must comply with relevant requirements.

(6) Power Leads

(7) Interface Loads and Support Equipment

It is likely that the user may not know if there is a remote load Transient Voltage Suppressor (TVS) present in the actual aircraft installation, or what TVS is used if one is present. However, since the support equipment may have some very expensive components in it, the user may choose to add TVSs to avoid damaging this support equipment. In this case the following guidance should be used when adding TVSs to the remote load end (refer to [Figure 22.UG-1](#) and [Table 22.UG-1](#)):

- It is always acceptable to use the exact transient protection on the remote load end if it is known.
- If it is expected that the EUT will interface with an LRU or multiple LRUs

- Where the exact TVS characteristics are not known, it is acceptable to select a single TVS turn-on value that is lower than or equal to the lowest turn-on value of the TVSs in the EUT. The intent is to assure that if the voltage rises high enough to turn on the EUT TVS the remote load TVS will be on, allowing full threat current to flow. This could be viewed as worst-case.
- Where the remote load TVS status is not known but the user wants to protect expensive support equipment, TVSs should be selected to protect that equipment that have lower than or equal to turn-on values than the lowest turn-on value of the TVSs in the EUT. Again, this assures that the remote load TVS will be on and conducting worst-case current if the voltage rises high enough to turn on the EUT TVS, but at the same time ensures protection of the support equipment components (the fragile components would most likely need a lower turn on voltage than the EUT, and not likely to be able to withstand any higher voltages than an EUT).

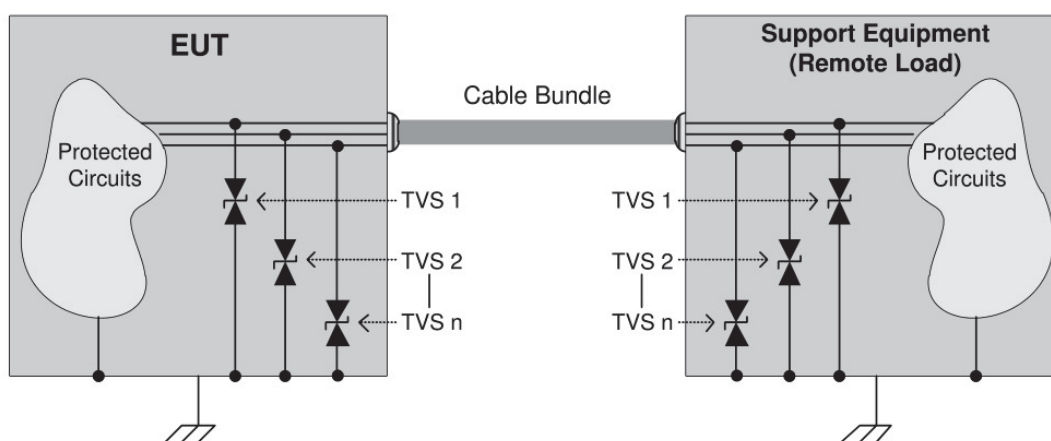


Figure 22.UG-1: Interface Loads and Support Equipment

Table 22.UG-1: Remote Load TVS

Case (Address by cable bundle)	Remote Load TVS		
	1	2	n
Remote load transient protection is known	Use known interface 1 transient protection, including TVSs	Use known interface 2 transient protection, including TVSs	Use known interface n transient protection, including TVSs
Remote load transient protection is unknown	Protect all lines with TVSs using a single clamping voltage that is lower than or equal to the lowest clamping voltage TVS in the EUT		

(8) Dummy Antennas or Loads

b. Test equipment

(1) Bonding

(2) Line Impedance Stabilization Network

The purpose of the LISN is to standardize the impedance of the power source that provides input power for the EUT(s). LISN(s) need to be used whenever the power source impedance could affect test results, such as lightning testing of the power leads. This control is needed because the power supply source impedance can vary from one facility to another for a variety of reasons, e.g. different power supplies, power line lengths, EMI filtering, wire size, etc. This stabilization ensures consistent results between test facilities. The LISN normally used for DO-160G EMI and lightning testing is a 5 μ H LISN which simulates the power line impedance of small-to moderate-sized aircraft; however this is not specified as a requirement. The impedance chart (Figure 22-9) is based on the impedance of a 5 μ H LISN.

The use of the 5 μ H LISN was driven by RF susceptibility, RF emissions and lightning tests in which procedures required testing below 150 kHz. Certain problems were observed with the 5 μ H LISN, such as a resonance near 70 kHz. This was resolved by adding the 10 μ F capacitor which moved the resonance down to approximately 20 kHz. Additional capacitance would further lower the resonance but would start to adversely affect 400 Hz power sources. Figure 22-9 illustrates the LISN impedance, with the external 10 μ F included. The impedance tolerance has been widened above 150 MHz due to measurement uncertainty. It should be noted that since the 10 μ F capacitor is necessary for meeting the impedance curve of Figure 22-9, this capacitor must also be included in the test setups. Additionally, Figure 22-17 shows additional capacitance across the LISN for DC testing. The purpose of this capacitance is DC power supply protection. This additional protection is generally not required for AC power sources and would increase the 400 Hz input current shunted through the capacitor to ground.

(3) Measurement Probes and Injection Transformers

Oscilloscopes

Some factors that should be considered when selecting an oscilloscope to measure lightning waveforms are:

- Oscilloscope Bandwidth
- Oscilloscope Sample Rate
- Oscilloscope Timebase and Memory Length

Oscilloscope Bandwidth

Oscilloscope Bandwidth (BW) is specified at the -3 dB point on the frequency response curve. Another way of expressing -3 dB is -29%. Therefore at the

bandwidth frequency, the amplitude measurement accuracy is -29%. The upper frequency of the bandwidth must be high enough to provide sufficient accuracy.

Oscilloscope manufacturers give the following guidance:

Use a BW in MHz $\geq 0.45/t_r$, where t_r is the 10% to 90% rise time of the waveform in microseconds (μ s). The amplitude measurement accuracy would still be -10% with this bandwidth. A BW $\geq 1/t_r$ improves the amplitude measurement accuracy to -2%.

For sinusoidal waveforms, $t_r = t_{\text{period}}/5$.

Examples:

For Waveform 3, 10 MHz sinusoidal measurements, $t_r = 100 \text{ ns}/5 = 20 \text{ ns}$:
Use a BW $\geq 1/20 \text{ ns} \geq 50 \text{ MHz}$.

For Waveform 2, ~80 ns rise time:
Use a BW $\geq 1/80 \text{ ns} \geq 12.5 \text{ MHz}$

Oscilloscope Sample Rate

Digital Oscilloscope Sample Rate is the number of data points recorded per second. Single-shot sampling is required to capture single triggered lightning waveforms. The sample rate must be high enough to provide sufficient accuracy.

Oscilloscope manufacturers give the following guidance:

To prevent aliasing, the Nyquist Theorem says you must have at least 2 samples per period in order to reconstruct the basic frequency information.

Most manufacturers recommend a minimum sample rate of two times $1/t_r$. This is also expressed as 10 samples per period.

Examples:

For WF3 10 MHz sinusoidal measurements, $t_r = 100 \text{ ns}/5 = 20 \text{ ns}$:
Use a Sample Rate $\geq 2 \times (1/20 \text{ ns}) \geq 100 \text{ MS/s}$

For WF2 ~80 ns rise time:
Use a Sample Rate $\geq 2 \times (1/80 \text{ ns}) \geq 25 \text{ MS/s}$

Oscilloscope Timebase and Memory Length

Timebase is the time per oscilloscope division. Memory length is the amount of sample memory per oscilloscope channel. The timebase should be adjusted to the minimum needed to display all the applicable waveform parameters of T1, T2 and damping. The memory length should be large enough to maintain the calculated sample rate.

Current and Voltage Probes

Some factors that should be considered when selecting a current and voltage probe to measure lightning waveforms:

- Probe Bandwidth/Frequency Response
- Probe Maximum Peak Capacity (single pulse waveforms)

- Probe Maximum rms Capacity (power lead measurements)
- Current Probe Saturation Limits
- Current Probe Transfer Impedance (voltage to current ratio)
- Current Probe Measurement Impedance
- Current Probe construction (fixed window vs. clamp-on)
- The Current Probe must be electro-statically shielded

Probe Bandwidth/Frequency Response

Ideally, the probe should have a flat (or as flat as possible) response, across the entire frequency range that is required. Many waveforms have frequency components of several MHz, and/or frequency components to accurately measure the calibration and test waveforms. For instance, in the low kHz, a probe with a broadband, yet flat frequency response is necessary for accurate measurements in the frequencies of interest.

Probe Maximum Peak Capacity

For Single Pulse waveforms, it is recommended that the peak capacity of the probe should be at least two times the expected peak to be measured, to ensure that the probe will not saturate and distort the waveform.

Probe Maximum rms Capacity

When tests are performed on a power lead that is carrying continuous AC or DC power, the maximum rms capacity of the probe must be considered. It is recommended that the rms current capacity of the probe should be at least two times the expected rms current level to be measured, to ensure that the probe will not saturate and distort the waveform.

Current Probe Saturation Limits

Current probes have saturation limits that should not be exceeded to assure correct current measurements.

For Single Pulses, be sure that the current probe is rated for the Current x Time product of the pulse.

For Example: WF5B Level 5 is $5000 \text{ A} \times 500 \text{ us} = 2.5 \text{ Amp-Sec.}$

For Continuous Waveforms, be sure that the current probe is rated for the Current / Frequency quotient of the pulse.

For Example: WF3 1MHz Level 5 is $640 \text{ A/1 MHz} = 0.001 \text{ Amp/Hz.}$

If the current probe manufacturer does not specify saturation limits, contact them with your waveforms for guidance on selecting the proper current probe.

Current Probe Transfer Impedance (voltage to current ratio)

Commercially available current probes have a transfer impedance that varies widely, typically between -20 dB (1:10) to 60 dB (1000:1). Transfer impedance is often referred to as the oscilloscope's probe factor or attenuation factor and may applied as either a dB factor or a current to voltage ratio. For example, 26 dB or 20:1 could be

applied for a current probe that develops 1 Volt across its connector for every 20 Amps of transient current. As described above, the transfer impedance should be a flat 26 dB across the entire range of the waveform's frequency components.

Selecting a current probe with a transfer impedance that is either too high or too low can result in over-driving or under-driving the oscilloscope. Since the test category current levels vary widely, different probes or probe/attenuator configurations may be required to protect the oscilloscope yet still display a clean and usable waveform.

Current Probe Construction

Care should be taken when using clamp-on current probes to make sure that contacts between the halves of the clamp-on current probe are clean and properly aligned to provide consistent contact between the probe halves.

Measurement Impedance

Commercially available current probes are typically designed to be used with a digital oscilloscope employing a measurement impedance of either 50 Ω or 1 M Ω . For accurate current measurements, always set the oscilloscope to the measurement impedance for which the current probe is designed.

Injection Transformer

As a general rule, any injection transformer (also known as a clamp, coupling transformer or injection probe) that will produce an acceptable voltage and current waveform during the generator verification procedure or during the actual test on the cable, is an acceptable injection transformer for the particular test waveform.

Some factors that should be considered when selecting an injection transformer for Cable Bundle and/or Pin Injection tests:

- Bandwidth / Frequency Response
- Saturation
- Injection Transformer Construction

Bandwidth / Frequency Response

Because injection transformers must be designed to efficiently transfer a transient waveform to the cable under test, without internal arcing or saturation that causes distortion of the waveform, and they must produce the proper rise time and duration of the test waveforms, there are always tradeoffs between performance and other factors such as convenience or versatility. This being the case, the bandwidth of an injection transformer is usually very limited, with a particular injection transformer being "tuned" to some degree for a particular waveform.

Proper design of an injection transformer, especially for tests at very high voltage and/or current levels, is sometimes considered to be "more art than science" and therefore has resulted in a variety of different designs that all generally have one thing in common – a particular transformer will work very well for a particular waveform, but will not always work well for other waveforms. Unique injection transformers or injection transformer configurations (e.g., different turns, air gaps, etc.) are usually required for each test waveform.

Note that the same injection transformer and configuration must be used for performance verification and testing.

Saturation

A typical limiting factor for an injection transformer is the saturation point. Care must be taken when selecting an injection transformer, so that the test waveform will be efficiently coupled to the cable or lead under test, without distortion of the test waveform due to transformer saturation. Proper construction material that is matched to the frequency components of the test waveform is required, especially at the highest test levels. Iron cores may perform better for the longer duration waveforms, and ferrite cores may be better for waveforms with faster rise times and shorter durations. Many different variations on these general themes are available from different vendors, and have also been “custom-built” by different testing laboratories.

When tests are performed on a power lead or bundle that is carrying AC or DC power current, the effect of the power current on the saturation point of the transformer must be considered. The power currents could cause saturation of the injection transformer, and distortion of the test waveform, even though the waveform verification procedure gave a waveform that was acceptable.

Injection Transformer Construction

Injection Transformers are not required to have electrostatic shielding.

A fixed-window injection transformer will typically provide better performance than a clamp-on injection transformer, but due to the nature of a typical Cable Induction test setup, a fixed window style injection transformer is usually difficult to work with. Again, there is a tradeoff of convenience for performance.

The other construction feature to note is that longer duration waveforms usually require an injection transformer with more ferrous material to avoid saturation or distortion. To handle a high level Waveform 5A or 5B test, an injection transformer constructed with about 500 pounds of iron is not unusual. On the other hand, an injection transformer used for Waveform 3 at 10 MHz may be a general purpose RF injection transformer that could also be used for RF Conducted Susceptibility testing, and is constructed with a few small ferrite cores weighing only a pound or two.

Commercially available injection transformers may have an input to output turns ratio that may vary from 5:1 to 1:4, with multiple steps in between. The various turns ratios allow for flexibility in matching the generator to the cable under test. Caution: Changing the turns ratio on an injection transformer may cause it to saturate sooner. Other injection transformers have a fixed turns ratio, typically 1:1 or 2:1. In general, using a turns ratio that will step up the current can be useful for a test on a shielded bundle using a waveform with a high current test level. Conversely, if the test is performed on an unshielded bundle, using a voltage waveform, with a high voltage test level, a turns ratio that steps up the voltage may be helpful.

c. Data Required In Test Report

- (1) Cable Configuration(s)
- (2) Test Setups
- (3) EUT Operating Mode(s)
- (4) Load(s)

- (5) Test Waveforms and Levels
- (6) Applied Transients
- (7) Pass/Fail Criteria
- (8) Test Results

22.UG.5 Test Procedures

22.UG.5.1 Pin Injection Tests

Applied Test Waveforms:

The test waveforms used in this section are idealized waveforms in lieu of actual measured transients. A discrepancy may appear as the result of a design which is “tuned” to the idealized waveforms and their respective source impedances.

As an example, if a lightning protection circuit inside the EUT uses the relation between its predicted impedance at the test frequency and the impedance of the source (impedance divider), this same design may be defeated when presented with a waveform constituted from a combination of double-exponential and oscillatory content in an actual installation as shown in Figure 22.UG-2.

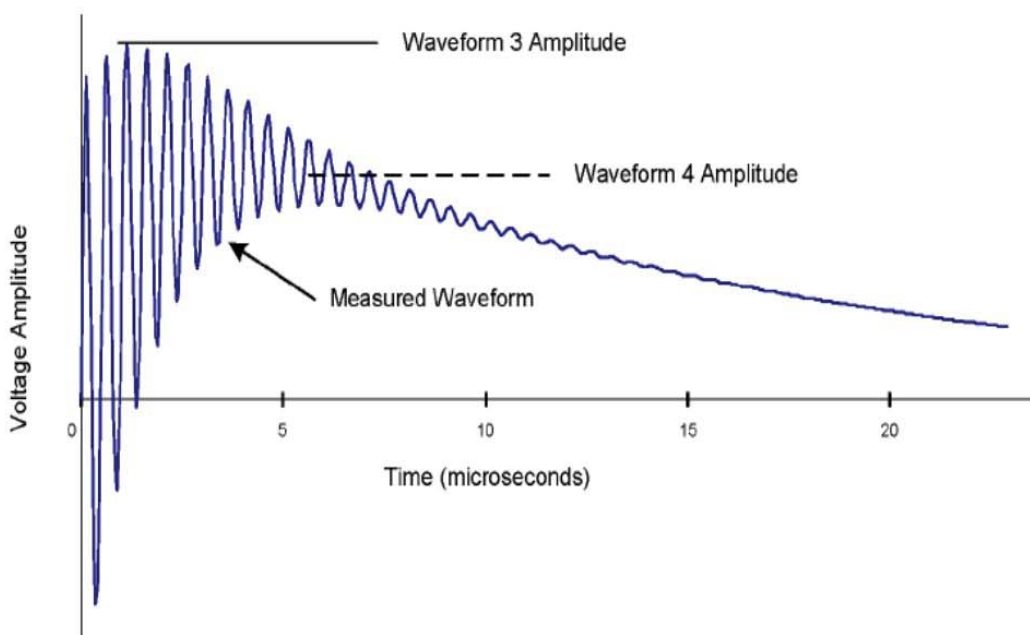


Figure 22.UG-2: Combined Double-Exponential and Oscillatory Waveform

For several good reasons, it is not practical, nor reasonable to require a combination test to be performed. However, consideration should be given to ensure that the design intent of the EUT takes into account the combinatory nature of the transients occurring in the real environment and the associated impedance versus frequency relationship.

a. Dielectric or high potential (hi-pot) tests

A dielectric withstand voltage or high potential (hi-pot) test may be used in lieu of the pin

injection test to verify the ability of electrically simple devices such as actuators, linear variable differential transformers (LVDTs), and speed sensors to demonstrate compliance to the pin test requirements. These simple electrical devices must be passive with no EMI filters or transient voltage suppressors (or other similar electrical circuit elements that are connected through case ground to aircraft structure). In addition, the dielectric withstand voltage test is applicable for electrical devices that are electrically isolated from case and local airframe grounds. In these cases, the interface signal and return wiring must be routed together (e.g. twisted pair) in the intended installation such that an insignificant line-to-line induced voltage results. The dielectric withstand voltage test voltage level is to be at least the peak amplitude of a level in Table 22-2. Note that when testing pins which normally have a bias voltage, i.e. power line inputs or other sources, this voltage must be added to the peak test voltage of Table 22-2. This test voltage may be applied from each pin to case or from all pins, simultaneously, to case.

The aircraft installation must always be considered when choosing whether to perform a dielectric test or a pin injection test. Some aspects of the installation, such as the use of local grounds or high impedance grounds, can have a significant effect on the environment the EUT will be exposed to on the aircraft. For example, if the unit is using aircraft structure as the ground return and that return is located close to the unit (e.g., local ground), then pin injection is the appropriate test to be utilized.

Example: Dielectric Withstand Voltage Test Procedures – Typical Test Sequence

1. Connect the dielectric withstand voltage test set between the designated pin(s) of the EUT and ground or chassis.
2. With a dielectric withstand voltage test set adjusted for the potential of the pin injection test level plus a bias voltage; take a 60 second leakage current measurement between the ground and the appropriate pin(s). The measured leakage current value shall be less than the pre-determined acceptable limit.
3. Discharge the voltage stored between chassis ground and the pin(s).
4. Repeat step 2 through 3 for each designated pin or group of pins in each connector of the EUT to which this test is to be applied.
5. DETERMINE COMPLIANCE WITH APPLICABLE EQUIPMENT PERFORMANCE STANDARDS.

The test report should include a description of the simple device, description of the test performed, the test equipment used, etc. Other similar dielectric withstanding test procedures may also be used to perform this test.

b. Pin Injection Testing Considerations

It is required, in most cases that the EUT is powered during pin injection, but it is not required to be connected to any external aircraft system. In this state, the software in the EUT will place its active I/O to a default state, which may not be representative of the conditions during a lightning event. Consideration should be given to the damage tolerance of interface circuitry in all potential operational states.

Figure 22.UG-3 illustrates a simplified circuit diagram of a Discrete Output interface, commonly called “Low-Side Switch”. In such an interface, the EUT can command the transistor, used as a switch, to either an opened or closed state. As such, the interface will

possess two (2) distinct states, each of which will yield a different nature to the application of a lightning transient.

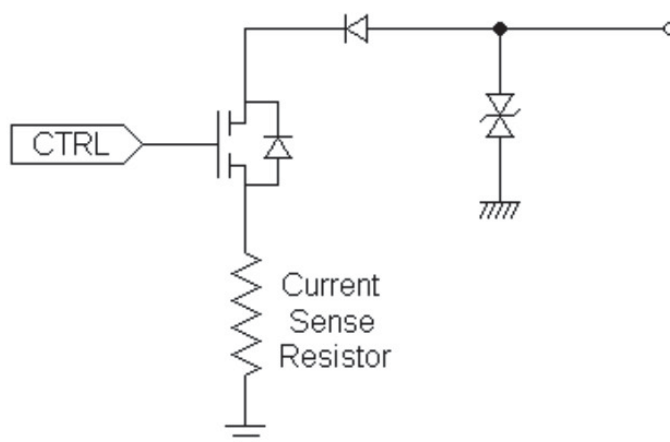


Figure 22.UG-3: Simplified Discrete Output Interface

Figure 22.UG-4 illustrates the case where a positive lightning transient would be applied to such a circuit when the transistor is commanded in the opened state. The resulting test will apply a voltage to the transistor terminals, testing its junction breakdown voltage capability. As for a Transient Voltage Suppressor (TVS) diode or any equivalent means of protection, it will be forced into breakdown and 100% of the source current will flow through this diode, resulting in a power dissipation test for that component.

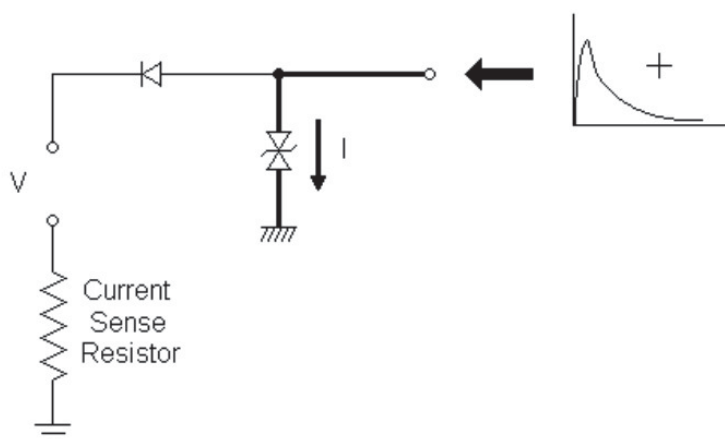


Figure 22.UG-4: Transient Applied on an Opened-State Circuit

In Figure 22.UG-5, the same transistor is in a closed state. The impedance presented to the lightning generator will now be very low, especially if the power ground plane is tied to the chassis of the EUT. In such a case, the transistor, sense resistor and series diode will all be exercised for their surge current capability. The voltage which then appears across the terminals of the sense resistor may not be sufficient, at least until the current level is very high, to turn ON the TVS diode. At that point, the TVS diode's dynamic resistance will establish a balance of current sharing between the two branches.

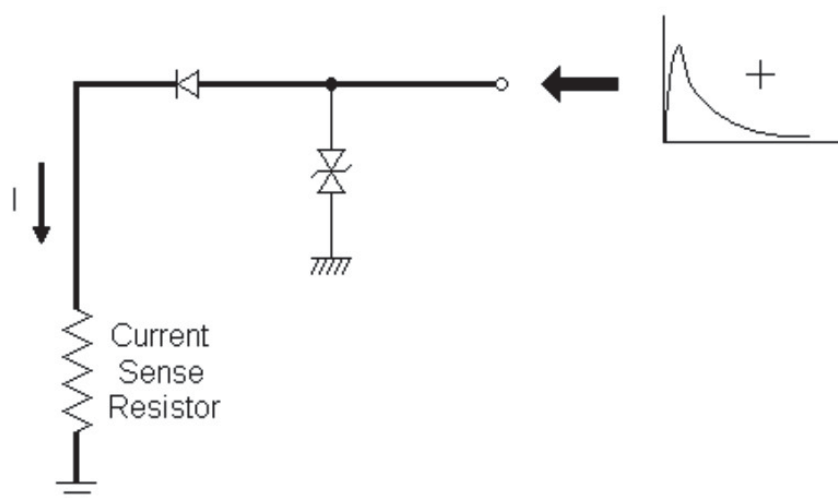


Figure 22.UG-5: Lightning Transient Applied to a Closed-State Circuit

Since each condition exercises different electronic component characteristics, it is conceivable that a given circuit design could tolerate the transient in one state and sustain damage with the same test applied in the opposite mode of operation.

c. Groups (Four or more) of EUT Circuits (Pins)

When allowing the use of similarity of interfaces for qualifying untested pins, similarity should not be based strictly on schematic definition of the circuit, but consideration should also be given to how the artwork or printed circuit board layout potentially affects the results of the test.

Some examples:

- The printed circuit board traces width and length from the connector.
- The printed circuit board copper thickness on the layers used to route each interface.
- The number, size and type of circuit board vias used in the path of each interface.
- The spacing between each circuit component of the interface (diodes, resistors, transistors, etc.).
- The spacing between each circuit traces and pads.
- The board temperature where the circuitry is located.

Depending on the impedance of the interface, pins may see predominately voltage or current. For predominantly voltage waveform tests (high impedance input), discrete electronic components will be tested for their ability to hold voltage without sustaining damage. In this case, the formation of an arc between any two traces, vias, pads or any other adjacent artwork components should be considered. For low impedance inputs where the signal is predominantly current, discrete electronic components will be tested for their ability to conduct surge currents without sustaining damage. In this case the fusing of a copper trace used as a conductor or a via on the printed circuit board should be considered.

d. Remote Load Impedance - Loading/TVSs/Impedances

Lightning transients predominately occur common mode (line to ground). Hence pin injection tests are conducted from line to ground to mimic the transient threat. As such, the common mode loop impedance will ultimately determine the loop current transient being driven by the impressed transient voltage. The following provides examples of common configurations:

1. If either end of a circuit (at the EUT or load end) is isolated from case or aircraft ground, then a high impedance loop exists and the current for Waveforms 4 and 5 is significantly reduced. Even if there is a TVS at one end whether it be the load or EUT, the loop impedance is still very high due to the isolation at the other/remote end. The term isolation in the remote load refers to a pin which has no electrical/electronic component installed from pin to case. This isolation is also only as good as the dielectric strength it is designed for. That is, if the isolated device or conductor has been designed for a 1000 V dielectric strength, the loop will remain at high impedance when transients with a peak voltage up to that voltage (1000V) are impressed on the circuit. In this case series impedance may be inserted between the generator and the pin to be tested. The voltage must be monitored on the EUT side (calibration point) during the pin injection tests per Figure 22-13 to ensure that the resistor has not been damaged during testing. A non-inductive resistor should be used for the series impedance to minimize the impact on the calibrated waveform.
2. If the loop presents a low impedance then there may be little to no impedance to limit the transient current. This low impedance will exist at both ends (EUT and load) of the conductor or circuit. In this case, series impedance should not be inserted between the generator and the pin to be tested.
3. If TVSs are used to provide protection and these devices are used at both the load and EUT ends, then low loop impedance exists. That is, when the TVSs have not “turned on,” high impedance exists. When the lightning transient voltage level exceeds the TVS clamp voltage, the TVS does “turn on” and it becomes a low impedance to shunt the loop current and minimize the voltage. Hence, if there is one at each end (EUT and load), the overall loop impedance is very low as both TVSs “turn on” and no limiting impedance exists. In this case, series impedance should not be inserted between the generator and the pin to be tested.
4. If the remote load impedance characteristics are unknown then series impedance should not be inserted between the generator and the pin to be tested.

e. Single devices used to protect multiple pins.

In some designs a single protection device may be used to protect multiple interfaces. In such cases, the single pin to case test might not account for transients appearing on multiple interfaces at the same time. An assessment of the protection device rating and/or test method may be required.

For example, steering diodes might be used on several pins and would redirect the transient to a single suppressor. This implementation is typically used to save printed circuit board area as the suppressors are larger than common diodes. An example of the implementation is shown in [Figure 22.UG.6](#). In this case, the current path for each pin will comprise its individual series and parallel components; however the transient current of all such lines will merge into a single TVS. It must be noted that such a design methodology may or may not use identical parallel circuits prior to the suppressor, and as such, current sharing assumptions should be limited.

As an example, shown below are three EUT interfaces that are routed to three pins on the EUT connector through the use of individual steering diodes. Each pin should be tested individually to stress the individual interface components and the group of pins should be tested simultaneously to stress the common components, in this case, the TVS. This approach may not be practical from a test standpoint, as it may not be possible to inject transients on all pins of concern in a simultaneous fashion without using several synchronized generators. As such, it will become impossible to adequately test the common TVS to its intended level. Analysis should then be used to ensure that the printed circuit board features and suppressor sizing is adequate to sustain the transient current of the combined interfaces.

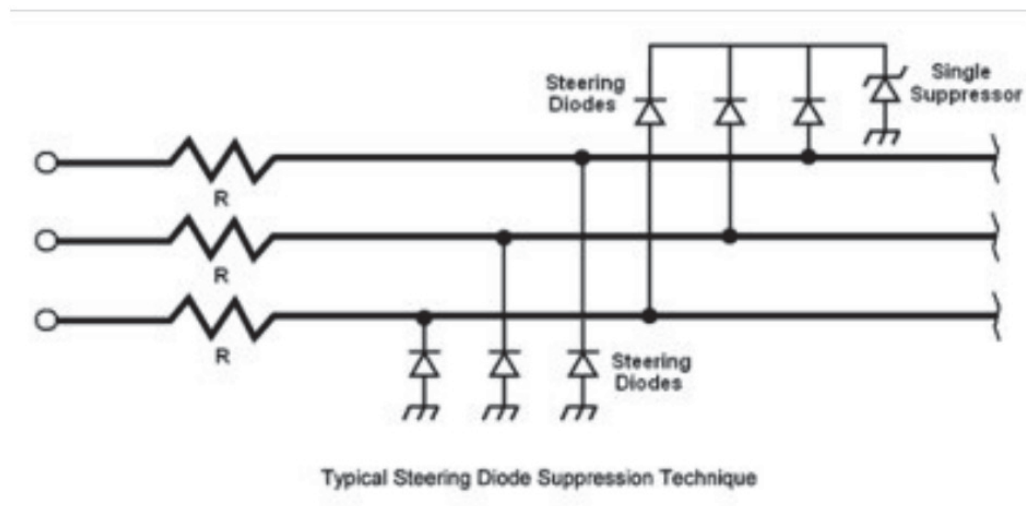


Figure 22.UG.6: Multiple Pins Protected by a Single Device

Applied Test Waveforms

The test waveforms used in this section are idealized waveforms in lieu of actual measured transients. A discrepancy may appear as the result of a design which is “tuned” to the idealized waveforms and their respective source impedances.

As an example, if a lightning protection circuit inside the EUT uses the relation between its predicted impedance at the test frequency and the impedance of the source (impedance divider), this same design may be defeated when presented with a waveform constituted from a combination of double-exponential and oscillatory content in an actual installation.

22. UG.5.1.1 Procedures - Generator Calibration

Pin Injection Generator Calibration

Previous versions of the pin injection calibration procedure specified the use of a non-inductive resistor method of impedance verification. This method does not demonstrate the waveshape generation capability in very low or short circuit conditions. As this is the preferred method of calibration and also to eliminate discrepancies in allowable tolerances between the two methods, the resistor method was removed as a verification method. The procedure continues to specify that the voltage waveform must meet waveshape requirements, but that the short circuit current only retain the general waveshape. This implies that specified waveform tolerances may be exceeded for short circuit current, which is due to limitations of some waveform generators. It is the intent of the test to deliver an equivalent amount of energy to the circuit under test and that this is consistent regardless of the generator being used. As such, deviations from the specified waveshapes should be minimized as much as possible. In cases where the short circuit current waveshape is not within specified tolerances the following guidance applies: For double exponential short circuit current waveforms, if T2 (decay time) is longer or T1 (risetime) is shorter, the waveshape is acceptable. If the decay time is shorter than T2 minus 20%, it is recommended that the test level be increased such that the T2 current is equal to 50% of the specified peak, not the measured peak. Likewise if the rise time is longer than T1 plus 20%, the test level should be increased such that the specified peak current occurs within that time period.

Additional Generator Pin Injection Source Impedance Verification

This is an additional verification check for the unlikely event that a generator would pass V_{OC} and I_{SC} but fail a resistor test for Pin Injection source impedance verification for example, if the generator is not linear.

In addition to the V_{OC} and I_{SC} tests defined in Section 22.5.1.1 to verify the generator pin injection source impedance at both extremes (V_{OC} , I_{SC}); a user can use a non-inductive resistor load as additional verification of the generator's pin injection source impedance.

This additional verification step would only need to be done once to verify that the generator output is designed correctly or if the user suspects a generator issue. This need not be performed continually for calibration or testing.

1. Set/measure the open circuit voltage of the generator/test leads at the V_{OC} test level with no resistor load.
2. Place a non-inductive resistor load (R) equal in value to the test waveform specified source impedance (V_{OC}/I_{SC}) on the output of the generator/test leads.
3. Measure the voltage drop across the non-inductive resistor (VR) with the generator at the same setting that produced the required V_{OC} in step 1 above. This voltage must be $V_{OC} / 2 \pm 5\%$ if the non-inductive resistor load (R) is within 1% of the test waveform specified source impedance (V_{OC}/I_{SC}). If R is greater than 1% of the test waveform specified source impedance (V_{OC}/I_{SC}), then compensate for R resistance error by using Ohm's law to determine if the actual generator source impedance (Z_{GEN}) is within $\pm 10\%$ of the specified (V_{OC}/I_{SC}).

$$Z_{\text{GEN}} = (V_{\text{OC}} * R / V_{\text{R}}) - R$$

Z_{GEN} = generator source impedance (Ohm)

V_{OC} = generator/test lead open circuit output voltage (Volt)

R = non-inductive resistor (Ohm)

V_{R} = Voltage measured across R (Volt)

For example, if you were performing a waveform 4, level 3 calibration, you would set the unloaded generator/test leads to produce a V_{OC} of 300 Volts and then place a <1% non-inductive 5 Ohm resistor (R) across the generator/test lead output and verify the voltage measurement across the resistor is 150 Volt +5% or if the non-inductive 5 Ohm resistor is greater than 1% tolerance (as measured with precision Ohmmeter), use the formula above to determine if the actual generator source impedance (Z_{GEN}) is 5 Ohm +10 %.

22.UG.5.1.2 Procedures - Test Sequence

- a. The statement “connect the calibration point to a designated pin of the EUT by means of a short, low inductance lead” is further clarified in Figures 22-13, 22-14, and 22-15 by stating the distance as ≤ 5 cm. In some cases it may not be practical to maintain this distance because of the length of interface wires connecting the generator calibration point to the pin under test. In this case, a representative interface wire or a wire of the same size and length may be added to the calibration setup during calibration.
- b. There is no required minimum time interval between pin injection transient applications. Waveform 3 is not considered a thermal stress concern, however, a minimum interval (not to exceed one minute) should be considered for the double exponential waveforms to avoid undue thermal stress.

22. UG.5.2 Cable Bundle Tests

- a. An interconnect cable bundle to be tested is typically associated with one connector, with the exception of power leads which are not necessarily included with the connector’s cable bundle.

Power leads are tested separately when aircraft installed power routing is different than the other interconnect wiring or is unknown. When a connector includes multiple power leads, such as DC power with remote return, AC power with remote return, or three phases.

AC power, the worst case typically is to test each power lead separately (including testing the remote returns separately), limiting the current level to the pin injection current level and then test the signal bundle without power leads. However, there are situations in which DC power leads should be tested both separately as well as together as an additional test to ensure the worst case is covered. For example, equipment may utilize multiple DC power line inputs fed from different power sources, whether entering one connector or multiple connectors, for reasons such as redundancy. In this situation, the power lines should be tested together, and the test current increased to the number of

power sources multiplied by the appropriate current test level. If multiple wires feed the power supply from the same source, as is the case where multiple wires are used to carry the power current using smaller gauge wire, then these wires should be tested together but the current limit does not exceed that of a single power wire. Grouping multiple interconnect cable bundles together during the cable induction test may not induce sufficient current in each individual interconnect cable bundle to satisfy installation requirements and therefore, is not recommended.

DC isolation of a remote load connected with a specific wire bundle is not sufficient justification to eliminate the cable bundle testing of that particular wire bundle because some level of differential mode transients may still be developed.

- b. During the cable bundle test, if the limit level (I_L or V_L) is reached before the test level (I_T or V_T) the procedure (paragraph 22.5.2.1.2i (1)) requires that the test must be evaluated for validity. If the generator used does not meet the specified limit criteria, the procedure states that a different waveform generator must be selected to complete the test.

When performing a current test, using WF1 and/or WF5, it is desirable to reach the current test level (I_T). For a low impedance wire bundle, this typically is not an issue and the I_T requirement is reached well before the voltage limit (V_L). However, in the event V_L is reached before the I_T , the user may be required to change generators. In this case, the user may elect to continue to increase the current waveform generator level before changing generators, depending on the level of over test that is acceptable. By increasing the generator level to I_T and evaluating performance at that level, the shielded waveform category and test level designation can be retained.

It is recognized that in many cases, this is not possible and that simply increasing the generator level until I_T is reached may be an overly severe test.

In a limited number of cases, such as those presented with a “hybrid wire bundles” (high impedance but with limited number shields), it is possible to fulfil the ‘requirements’ of the test, i.e. reach V_L with a compliant Waveform 2 or Waveform 4 generator, while not meeting the full intention of the test, which is to transfer the required power onto the bundle. One reason for this involves the method used to measure the voltage across the injection transformer’s open loop. Current flow through the secondary winding of the transformer (i.e. the cable bundle under test) can result in an artificially high open loop voltage measurement relative to the voltage transferred onto the core wires of the actual EUT interface.

If the voltage waveform has been shown to be compliant during the current test generator performance verification and the V_L is reached during the test, this is considered to be a valid test. However, as discussed above, this does not necessarily result in the proper core wire voltage and again, does not fulfil the overall intention of the tests. If driving the current waveform generator to I_T is considered too severe, it is suggested that the power from the generator be increased, exceeding the compliant Waveform 2 or Waveform 4 V_L , until the current level reached is at least 75% of the I_T . If this also results in an increase in power from the generator such that the compliant Waveform 2 or Waveform 4 voltage level is excessive and there is a threat of equipment damage, it is suggested that the shields be removed and a voltage test conducted using the appropriate voltage waveform (Waveform 2 or Waveform 4) and test level requirements.

Achieving an acceptable level of induced current in a shielded cable bundle can be very challenging on hybrid cable bundles, which by definition can include only a single shielded wire. If the user attempts to meet the intent of the test by following the process described above and continues to drive the generator to excessively high levels without meeting the suggested levels, then the selected waveform set should be re-evaluated as they are likely not valid for the proposed installation.

This process is depicted in [Figure 22.UG-7](#).

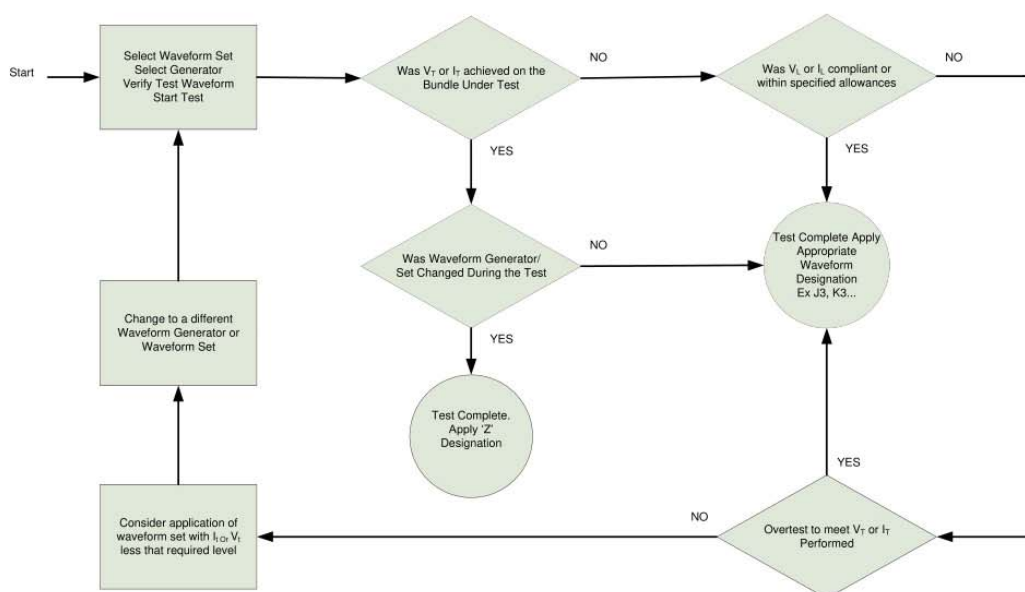


Figure 22.UG-7: Waveform Test Process

The voltage magnitude associated with each test level is the same for the pin injection tests and the cable bundle tests. The associated currents for cable bundle testing are higher because they reflect injection on multiple conductors rather than the single conductor for pin injection. When testing an individual conductor using cable induction, it should be recognized that this is normally a more severe test, in that the test generator is adjusted to meet the test level (V_T or I_T) as opposed to the controlled source impedance generator methodology used for pin injection. Note that as specified in the test requirements, the only situations in which a conductor is expected to be tested individually are the cases of power leads and of single conductor connectors.

When a cable bundle contains a relatively low wire count, the cable bundle test may also be more severe than the pin injection test because there are fewer wires to distribute the induced cable current. The wire count where this severity threshold occurs is dependent upon the waveform that is being applied. For example, the Waveform 1 current test level (I_T) is a factor of 10 times the corresponding Waveform 4 pin injection short circuit current (I_{SC}). In the case of Waveform 5A, the ratio varies from 2.67 to 3.33 times the individual pin I_{SC} , depending on the test level selected.

Where cable bundle test individual conductor currents could significantly exceed the pin injection test ISC, such that overstressing pins is a concern, the percentage of the total current may be scaled to not exceed the individual pin short circuit current level. If the user scales the current, this may be acceptable for the proposed installation; however, a standard cable bundle test has not been performed and the test level designation must be designated as a 'Z'. There should be no distinction between shielded or unshielded wires when establishing the number of conductors for scaling purposes.

Antennas represent a case where there may be a connector with a single conductor. Since antennas are normally installed in high threat areas, scaling the current is not recommended.

Applicability of Waveform 6

Current Waveform 6 is present as a response to current component H in the lightning multiple burst waveform set. Current Waveform 6 will be present on the shields of well terminated, e.g., 360 degree shield to connector terminations, shielded cables interconnecting system equipment. Also, in order for current Waveform 6 to be the response to current component H, loop areas and impedances (cable lengths, connector termination, low impedance enclosure connections to the "ground plane", etc.) must be small enough that in the frequency domain, the transfer function for current component H to current Waveform 6 coupling is flat. In other words, the frequency content of current Waveform 6 will be that of current component H over the current component H range of frequencies of interest.

If loop areas and impedances are such that current Waveform 6 will not be the response, the rise time of current component H is fast enough that interconnecting cable lengths will appear to be "electrically" long or impedance mismatched and the response will be voltage/current Waveform 3.

Low Impedance cables that may require Waveform 6 application are typically located in regions of the aircraft that are electromagnetically exposed or where resistive coupling may predominate. Examples of regions where Waveform 6 may need to be evaluated include landing gear regions, engine installations, flight control surfaces, wingtips, or empennage regions. Generally, regions within the fuselage or wing structures will not have significant coupling of the Waveform 6.

22.UG.5.2.1 Cable Induction Tests

22.UG.5.2.1.1 Procedures - Generator Performance Verification

22.UG.5.2.1.2 Procedures - Test Sequence

- a. It may be necessary to pass the cable bundle under test through the injection transformer for multiple turns in order to reach the voltage test level (V_T) during the EUT test. For accurate voltage measurements, the open voltage monitor loop number of turns must match the EUT cable bundle number of turns. The default, as shown in Figure 22-17, is one turn (1 pass), which is adequate in most test situations. However, it is acceptable for voltage waveforms only, to increase the voltage to current ratio by using multiple EUT

cable bundle and open voltage monitor loop turns. This technique should never be used to reach the voltage limit (V_L) during current waveform tests.

b. Transient Amplitude Determination

Introduction

Transient amplitude determination can be a significant source of test variability and error. The techniques used not only determine the susceptibility threat level applied to the EUT, they are also the basis of timing measurements that determine whether the waveshape is compliant during generator calibration/verification. Variability and error can be minimized by using consistent oscilloscope measurement techniques when making transient measurements. The following guidelines are intended to assist with transient amplitude determination when using a digital storage oscilloscope:

- i. Use cursors, not automatic measurement functions.
- ii. Select the proper time scale.
- iii. Properly place cursors in the presence of high frequency noise and loading effects.

Use of Cursors

Whenever a voltage or current transient amplitude measurement determines the level applied to the EUT, including the pin injection test's generator calibration, cable bundle test's generator performance verification, and cable bundle test's test sequences, peak amplitude should be determined by manually placing the oscilloscope's horizontal cursors rather than by using automatic measurement functions which just report the absolute peaks. For the pin injection test's test sequence, amplitude is measured for information only, so automatic measurement functions are always acceptable because the level applied to the EUT has already been determined by that point.

The possibility of under-testing is the reason the use of cursors is advisable when the measurement determines the level applied to the EUT. Transient characteristics described in this section such as high frequency noise and the inductive kick effect, which are not uncommon, cause the absolute peak of the transient to be higher than the actual transient amplitude. If a transient is free of these characteristics, both measurement techniques will yield the same amplitude.

Time Scale Selection

The second key to consistent transient amplitude measurements is to choose the proper time scale. This improves consistency in the identification of high frequency noise versus the transient being measured.

During generator calibration/generator performance verification, the time scale should be set to the minimum time per division which displays all of the waveform parameters necessary to show compliance. For example, for most oscilloscopes, 1 μ s per division is the minimum time scale which displays the required waveform parameters for Waveform 3 at 1 MHz per Figure 22-4. Depending on transient generator design, the open circuit voltage and short circuit current time scales may be different.

During the cable bundle testing EUT test sequence, the same time scale established during generator performance verification for the voltage or current that is leveled to should be maintained. With Waveform 1, when I_T is reached prior to V_L use the time scale established during short circuit current, for example 10 or 20 μs per division would be appropriate. When V_L is reached prior to I_T , use the shorter time scale established during open circuit voltage, such as 4 μs per division.

Cursor Placement in the Presence of High Frequency Noise and Loading Effects

High Frequency Noise

One transient characteristic that may appear during generator calibration/generator performance verification or as a loading effect during the EUT test sequence is high frequency (high with respect to the intended transient's frequency components) noise. High frequency noise can appear on the leading edge and/or peak of both damped sine and double exponential waveforms and it should be ignored, not given credit.

Figure 22.UG-8 is an example of correct amplitude determination of a Waveform 3 damped sine transient with high frequency noise. The narrow spike on the peak of this transient's first cycle is the high frequency noise which should be ignored during amplitude determination. The narrow spike gradually opens as amplitude decreases, requiring a subjective judgment of where to place the cursor. The narrow spike should be minimized or not exist during the generator calibration/generator performance verification, but may be unavoidable as a loading effect during the EUT test sequence

As shown in this example, place the cursor at the peak where there is some discernible energy under the curve. This discernible energy under the curve amplitude determination criterion illustrates the importance of time scale choice. An alternative method for amplitude determination is shown in Figure 22.UG-9. In this example the cursor should be placed where the profile of exponential decay of peaks intercepts the first cycle. This can be performed subjectively or using the following, or equivalent, formula.

$$V_{P1} = V_{P3} \left(\frac{V_{P2}}{V_{P3}} \right)^{\left(\frac{5-1}{5-2} \right)} = V_{P3} \left(\frac{V_{P2}}{V_{P3}} \right)^{\left(\frac{4}{3} \right)}$$

Figure 22.UG-10 is an example of correct amplitude determination of a Waveform 4 double exponential transient with high frequency noise. Loading effect high frequency noise is present both as the narrow spikes on the leading edge and peak of the transient and as a hash around the decay of the transient. Since the double exponential test transient is masked by high frequency noise, a curve was drawn to represent the test transient based on the general underlying waveshape, which may differ from the generator calibration/generator performance verification waveshape. As shown in this example (and similar to Figure 22.UG-10), place the peak amplitude cursor at the peak of the curve representing the test transient. Understand that there is energy under the curve which is masked by the noise, in order to avoid overly conservative cursor placement at the base of the noise. The curve representing the test transient may be drawn on a printed waveform or may only be drawn mentally by an experienced operator. Ideally, transient

generators do not produce even close to this amount of high frequency noise during generator calibration/generator performance verification, but some amount may be present. In this case, base the 50% amplitude point which determines T2 on the peak amplitude cursor.

In both of these examples, the subjective judgment of the test operator is required, but that is unavoidable. The use of an automatic measurement function for either transient would result in amplitude over-reporting, an unacceptable under-test if the measurement determines the level applied to the EUT. Careless cursor placement can result in amplitude under-reporting, an unnecessary over-test.

Loading Effects

In general, amplitude determination of transients with loading effects is no different than amplitude determination of transients that follow the ideal damped sine or double exponential waveforms: the peak of the transient is the amplitude if there is discernible energy under the peak.

For example, [Figure 22.UG-11](#) is a Waveform 5A double exponential transient with two notable loading effects- ripple and high frequency noise. Ripple should only be present as a loading effect, not during generator calibration/generator performance verification, if the generator is well designed. Ripple can appear on damped sine and double exponential waveforms, with or without higher frequency spikes included. Like most other loading effects, the peak of the test transient is the peak of the ripple, but high frequency noise should still be ignored. In this example, the upper cursor gives credit for the high frequency noise and is therefore incorrect amplitude determination that results in an under-test. The second cursor is correct amplitude determination because it ignores high frequency noise as described above, yet gives credit for the peak of the ripple. Like [Figure 22.UG-10](#), a curve was drawn between the peaks of the ripple as another example of representing the test transient based on the general underlying waveshape, which may differ from the generator calibration/generator performance verification waveshape.

The most common damped sine loading effect is the inductive kick effect, which arises because of the ability of inductance in the load circuit (EUT) to store energy initially upon discharge of the transient generator. The stored energy is released later in the cycle, increasing the charge on the generator's tank capacitor above the open circuit level. The result is subsequent peak(s) of higher amplitude than the first peak and of higher amplitude than the generator was charged to, as shown in [Figure 22.UG-11](#). Amplitude determination of the inductive kick effect is a special case. The procedure below is a best practice for determining the method to level the generator and determine amplitude:

Increase the generator amplitude until the verification peak is equal to the requirement or until the highest subsequent peak is equal to the requirement + 20%. In other words, exceed the requirement by up to 20% in an attempt to meet the requirement with the first peak. Record the amplitude of the highest peak the selected polarity, which is at some amplitude between the requirement and the requirement + 20%.

Figure 22.UG-12 is an example of a positive polarity Waveform 3 cable bundle test. Since the second positive peak is more than 20% higher than the first positive peak, record the amplitude of the second positive peak, which is currently at the requirement level + 20%.

Figure 22.UG-13 is an example of a negative polarity Waveform 3 cable bundle test.

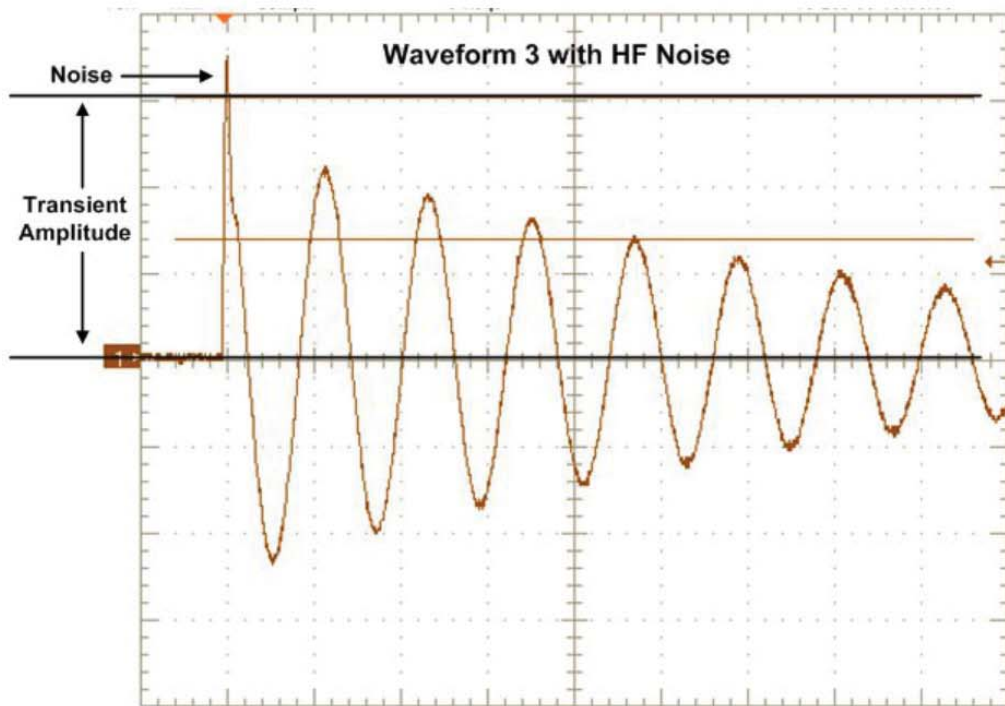


Figure 22.UG-8: High Frequency Noise - Waveform 3 Amplitude Determination

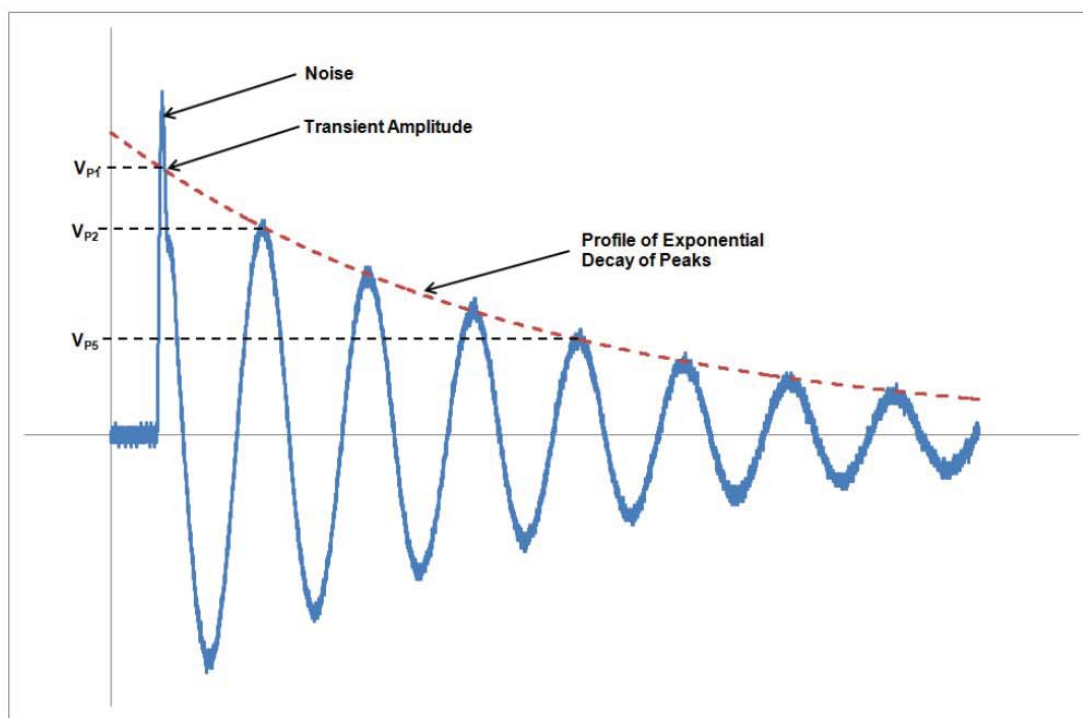


Figure 22.UG-9: High Frequency Noise - Waveform 3 Amplitude Determination

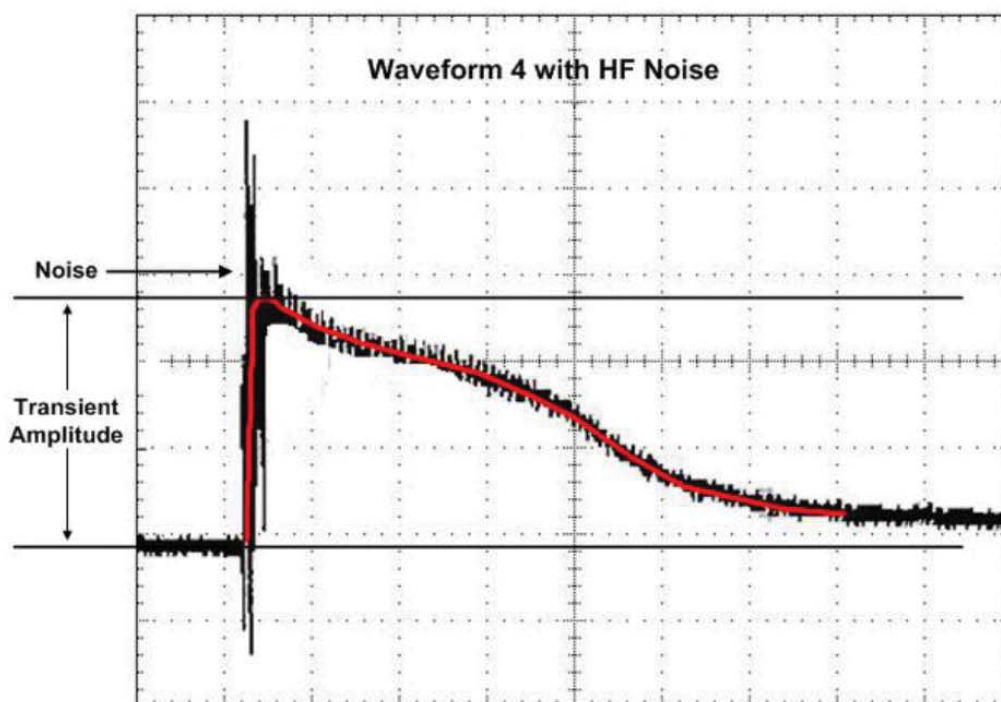


Figure 22.UG-10: High Frequency Noise - Waveform 4 Amplitude Determination

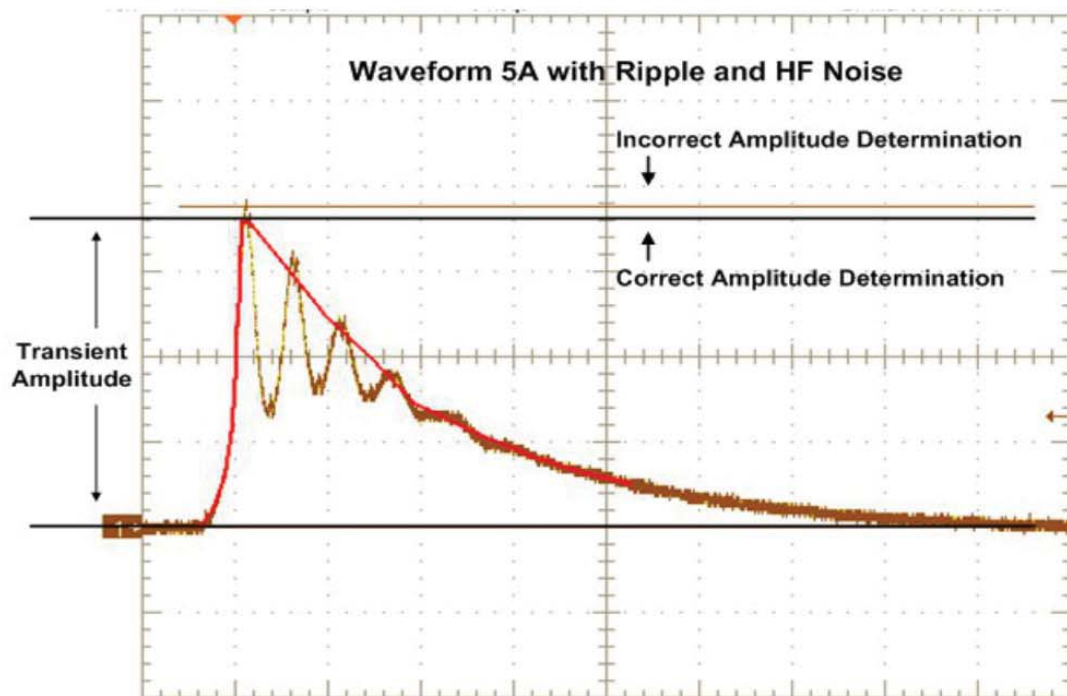


Figure 22.UG-11: Ripple with HF Noise - Waveform 5A Amplitude Determination

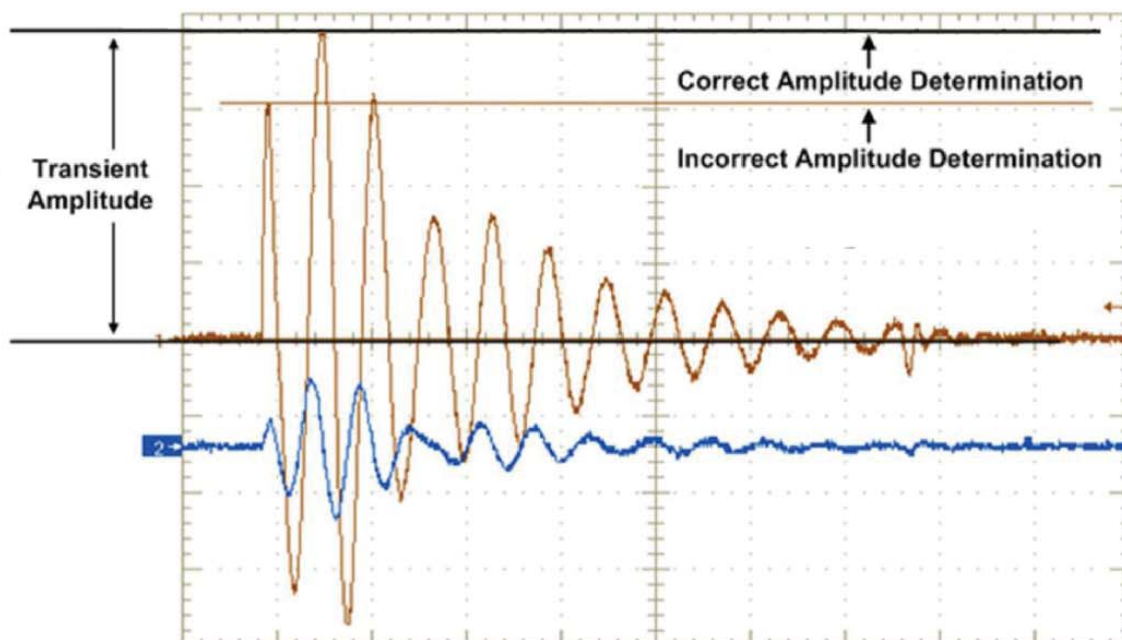


Figure 22.UG-12: Positive Inductive Kick Effect - Waveform 3 Amplitude Determination, Positive Polarity Applied

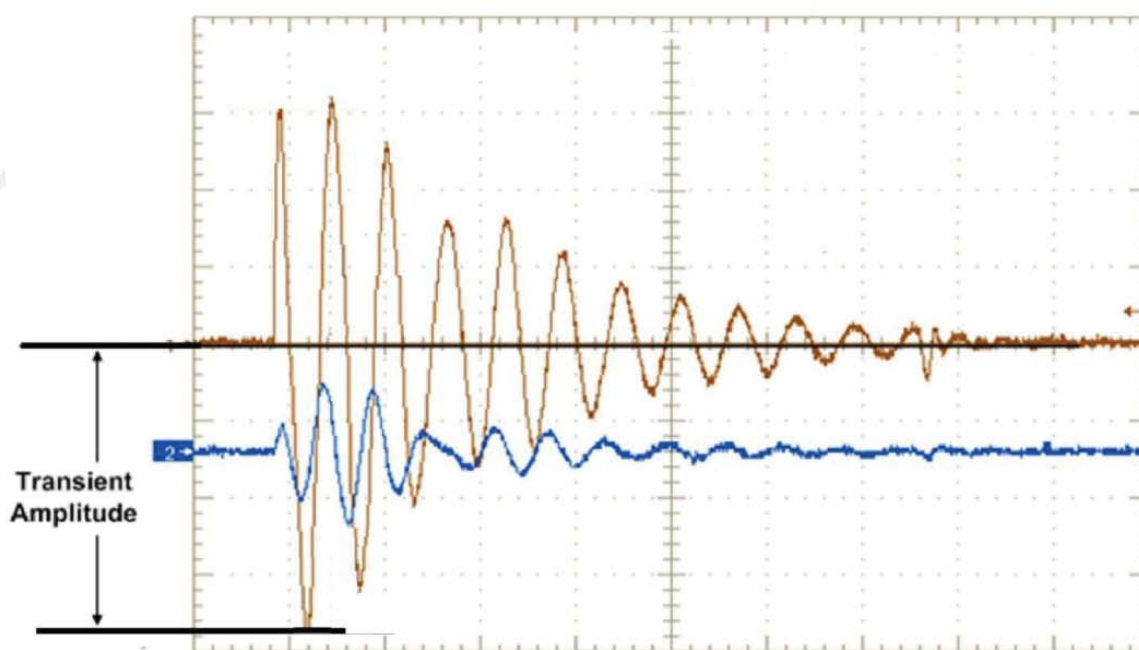


Figure 22.UG-13: Negative Inductive Kick Effect –

Waveform 3 Amplitude Determination, Positive Polarity Applied

22.UG.5.2.2 Ground Injection Tests

22.UG.5.2.2.1 Procedures - Generator Performance Verification

22.UG.5.2.2.2 Procedures - Test Sequence

Undershoot of Double Exponential Waveforms

Section 22 figures show idealized double exponential waveforms which do not define undershoot. Equipment manufacturers should be aware that significant undershoot may occur in actual aircraft installations and may also occur as a by-product of the cable bundle test method. If this occurs during cable bundle testing as a result of the natural response of the cable bundle to the applied waveform (the undershoot was not present during generator calibration), this undershoot should not be limited with an external clamping device on the test setup.

Note 1 of Figure 22-10 addresses the situation where the applied positive transient may occur during the negative swing of the AC sine wave, resulting in the peak value of the transient (measured with respect to the chassis ground) being significantly lower than the specified test level. This situation can be avoided if the applied transient is synchronized with the peak of the AC power input; where for a positive transient all 10 applications should occur during the positive peak of the AC sine wave and for a negative transient all 10 applications should occur during the negative peak of the AC sine wave.

DO-160G

**Environmental Conditions and Test Procedures
for Airborne Equipment**

User Guide for Section 23

Lightning Direct Effects

**Based on
DO-160G Section 23**

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23.UG.0 **Lightning Direct Effects**

23.UG.1 **Purpose of Tests**

Section 23 of DO-160G addresses testing of externally mounted equipment for the direct effects of a lightning strike. It is intended to provide a test environment and test procedures that are consistent with current industry practices. It is the responsibility of the component manufacturer and/or the aircraft integrator to make sure the test results satisfy the certification requirements of the proposed installation. This user's guide does not contain requirements; it is intended to provide background information and considerations that improve the likelihood of successful test design and implementation, ultimately providing consistent and interpretable results.

23.UG.2 **Definitions**

Action Integral/Charge Transfer

The action integral is a defined value that is associated with high current components A and D. The action integral is the integral of the square of the time varying current over its time duration. It is usually expressed in units of ampere squared seconds ($A^2\text{-S}$). It represents the energy dissipated by the lightning current in a unit resistance (expressed also as Joules/ohm). The charge transfer is also a defined value that is associated with high current components B, C, and C*. The charge transfer is the time integral of the current over its entire duration and is expressed in units of Coulombs (C) or Amp-seconds (A-S). This value is proportional to the energy transfer through the test article/generator system. It represents the energy transferred to the material surface by the arc root and can produce burning and erosion effects.

This assertion comes from the notion that the energy transferred through the system is defined by:

$$E = P \cdot t = V \cdot I \cdot t = I^2 \cdot R \cdot t$$

$$\text{Therefore, } (I^2 \cdot t) \cdot R = E$$

This means that should we know the resistance of the current path, we would know the energy transferred through the system. (i.e. the action integral is a proportional representation of energy transfer through the system.

Arc Root

An arc root is the location on the surface of a conducting body at which the lightning channel is attached where high current flows. On an aircraft, there will be both entry and exit arc roots.

For an aircraft trailing edge (i.e., the exiting arc root) the arc root may remain relatively stationary during the duration of the lightning flash. For a leading or intermediate surface edge, however, the attachment will remain in a single location for only a short period of time before sweeping back with the motion of the aircraft. These effects are tied directly to the institution of lightning zones on the aircraft.

The damaging effects of a lightning strike may be significantly altered by the character of the arc root (which may be altered by various surface treatments to the attachment surface). Dielectric surface treatments can serve to concentrate the current to a small point (should there be a micro porosity in the surface treatment). This can cause greater

damage than would be expected on an exposed aluminium surface. Expanded copper mesh surface treatments on composite materials can cause the arc root to be diffused over the attachment surface (thus decreasing the damage occurring at the arc root).

Attachment Point

In terms of testing related to this section, the attachment point is the location that is determined by performing the high voltage test or by analysing the test item as to how a lightning strike would attach in actual flight conditions. This location is where the high current is to be applied.

Continuing Current

This is referred to as component C or C* in the high current test section. This component is primarily associated with ohmic heating of the conductive substrate. It is responsible for the creation of “hot spots” that may be fuel tank ignition sources or a continued material degradation due to longer duration heating.

Corona

Corona is one of the initial steps involved in the breakdown of a dielectric media. This occurs when the voltage is high enough to ionize the surrounding air, but the voltage is not high enough to create a cascade breakdown of the dielectric media. As voltage is increased, the bleed current of the corona will increase until such a point that the voltage is sufficient to attain an electron cascade failure of the dielectric media.

When working around high voltage generators in the laboratory, corona can be detected audibly as a continuous hissing sound. It can also frequently be seen by dark-adapted eyes as a bluish glow extending some fraction of an inch from conductors, especially at corners. Equipment should not be approached by personnel when this condition is detected. The equipment should be discharged to ground and made safe prior to inspecting the equipment.

Discharge

High current discharges will span gaps of 50 mm or greater. High voltage discharges will have gap distances from 12 mm to greater than one meter, depending on the test method.

First Return Stroke

This would coincide with the Category 1 waveform requirements which includes high current waveforms A, B, C, C* and high voltage waveform D.

Flashover

The condition when the arc produced by a gap breakdown passes over or close to a dielectric surface without puncture. This is a common occurrence during the performance of high voltage testing. An example of a flashover produced in a lightning laboratory is shown in [Figure 23.UG.1](#) below.

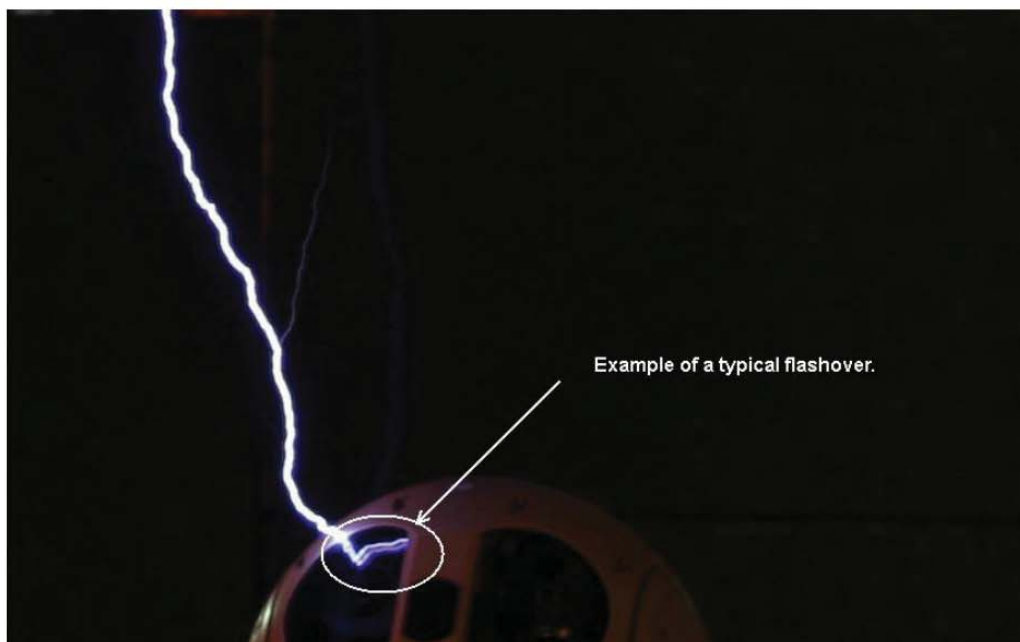


Figure 23.UG-1 - Example of a typical flashover

Gap Breakdown

In the case of the high voltage or high current tests, the breakdown would be between the electrode and the test object which is connected to the generator return.

Hot Spot

This would be caused primarily by the duration of the continuing current component C or C^* . The heating effects of this waveform could create a temperature that will ignite the gas mixture.

Intermediate Current

This is referred to as component B in the high current test section.

Leader

Following the initiation of corona in a dielectric media, continued increase in voltage allows the cascade breakdown of the dielectric media. This phenomenon is manifested through the creation of a leader (an ionized channel that propagates in a step-wise manner between the anode and cathode [or charge source and ground plane] of the discharge system).

Lightning Flash

The entire lightning flash can be discharged on a point on the trailing edge of an aircraft. The leading and intermediate edges/surfaces of the aircraft will typically be subjected to only a portion of the total lightning flash (thus the institution of lightning zones on the aircraft).

Lightning Stroke (Return Stroke)

The initial or first return stroke of a lightning flash will typically have the highest current amplitude. Subsequent return strokes can happen naturally (as a phenomenon of the charge migration within the charge source [cloud]) or can occur due to disruption of the lightning channel (as an aircraft flies through the lightning channel, the channel can be disrupted at which point a new leader must form to reinstitute the channel at which point the lightning will reattach).

Puncture

Puncture of a dielectric surface makes it more susceptible to further attachment/damage in the future. Punctures can result from high voltage or high current testing.

Streamers

Branch-like ionized paths associated with corona that occurs in dielectric media when high voltage is introduced (as on an electrode). With sufficient energy applied, multiple streamers combine into a luminous heated pathway, forming a leader channel step. An example of a streamer produced in a lightning laboratory is shown in [Figure 23.UG.2](#) below.



Figure 23.UG-2 - Example of a typical streamer

Swept Channel

As discussed in Lightning Stroke (Return Stroke) above, the motion of the aircraft relative to the lightning channel can cause the lightning to be disrupted and reattach to a place further along the axis of the aircraft.

Thermal Sparks

Thermal sparks can be either black/grey body or chemically reactive in nature. The black/grey body sparks are essentially non-reactive sparks that transmit energy by radiative emissions. The chemically reactive sparks can also emit energy through radiative emissions but are classified by their reactivity with the ambient environment. A thermal spark occurs between electrodes which are in contact with each other and carries excessive current which results in melting at the contact points. It results in an electric arc plasma and/or an ejection of molten or burning material.

Voltage Spark

A voltage spark is produced between electrodes which are initially separated and is initiated by a potential difference which causes an electrical breakdown of a dielectric, such as a fuel/air mixture.

23.UG.3 Equipment Categories

Categories in this section are directly related to the aircraft zoning requirements. For example, Category 1A equipment is tested and qualified in a Zone 1A environment. Tables 23-1 and 23-2 identify which waveforms are required for each category.

23.UG.4 General Test Procedures

High voltage attachment and high current test procedures are described in this section. It must be remembered that performing these tests is extremely dangerous and all safety precautions must be strictly followed.

The high voltage test is performed either to evaluate the dielectric breakdown performance of a material or to determine the likely attachment point of a lightning flash to an aircraft structure. Note: The likely attachment point is not to be interpreted as the only attachment point. In testing as well as in actual aircraft use, electric field gradients may be present with a range of orientations that could impact attachment points. Further, leader development is a stochastic process and attachment may vary from shot to shot even without a change in orientation.

The high current test is performed to determine how much damage may occur during an actual lightning strike. This test is often applied to the arc entry point determined by the high voltage test. If the high voltage test indicates that no entry point exists (i.e. it doesn't attach to the test article) then it is still typically required to perform a high current test. This can be done by connecting to a structural attachment point such as a mounting screw. If there are multiple choices for this connection, the worst-case option should usually be chosen.

23.UG.4.1 High Voltage Strike Attachment Testing

The two types of high voltage tests are described in this section – initial leader attachment and swept channel attachment.

23.UG.4.1.1 High Voltage Test Waveforms

High voltage attachment tests are performed using either voltage waveform A or voltage waveform D, depending on the category of the equipment being tested.

23.UG.4.1.2 Initial Leader Attachment Test**23.UG.4.1.2.1 Test Purpose**

This test is performed in order to determine dielectric performance of a test object. In cases where the test object has no dielectric covering and the worst-case location for a high-current test is readily identified, then this test may not need to be performed.

23.UG.4.1.2.2 Test Object

One of the most important things to consider is the return path connections. All of the test objects fastening or connection points to ground should be utilized to properly replicate an airframe installation.

23.UG.4.1.2.3 Test Fixture

As with the test object, the test fixture should be configured such that the connections to ground are similar to how the test object is installed on the aircraft. Additionally, the geometry of the aircraft installation can modify the local electric field (and therefore alter the behaviour of the approaching leader). In order to perform a test that produces relevant results, it is advisable to represent the aircraft installation as closely as possible (in terms of geometry as well as materials).

23.UG.4.1.2.4 Test Setup

The test electrode should be sufficiently large enough relative to the test sample to prevent breakdown off of the electrode edge.

With respect to ground connections, a multi meter should be sufficient to ensure that the connections are good.

Photography of the arc attachments and leader paths can be done with a conventional SLR (Single Lens Reflex) camera using a long time exposure (i.e., sufficient to trigger the high voltage bank). Room lights can be dimmed to improve contrast. The arcs in leader attachment tests are usually of relatively low current and brightness so little or no filtering should be required.

23.UG.4.1.2.5 Test Waveforms

High voltage generators are usually built with a relatively low capacitance, which limits the available current and charge transfer. Peak currents of 1000A are usually sufficient. If the current from the generator is too high, the higher current would create a much larger and brighter arc channel that would make it difficult to identify streamering and attachment points.

With regards to the voltage waveform, the rise time will be a function of the gap distance between the electrode and test object. There will be times where the gap distance will need to be increased in order to achieve a rise time that equals or exceeds 50 microseconds. The increased gap slows the time to breakdown through one or more processes involved in streamer growth, such as the drift velocities of ions. Leader steps in natural lightning occur on roughly a 50 microsecond time scale, which is enough time for the growth of a space-charge regions around a grounded air terminal or test object. This tends to reduce the attraction of the approaching leader to any very small or high-radius features. If the test setup is not modified to maintain the 50 microsecond time to breakdown, there is a possibility that attachment will be made to small features that would not be characteristic of the response in natural lightning.

23.UG.4.1.2.6 Measurements and Data Recording

Camera locations must be chosen so that they will not be damaged during the performance of the test. It is recommended that the camera tripods not be placed on the ground plane as this will increase the chances that the cameras will be damaged.

23.UG.4.1.2.7 Test Procedure

Laboratory environmental conditions to measure and record should include temperature and humidity at the beginning of the test day, and preferably also at the end of the day, especially if there have been changes in weather. Very high or very low levels of humidity can have a significant effect on high voltage tests.

When performing this test, it will be found that the positive polarity test will be very difficult to perform and requires modification of the geometry of the electrode, such as are described in the next paragraph. Such modifications are necessary to alter the electric field gradient enough to achieve breakdown of the voltage arc. The other issue that will be encountered is that it might be necessary to reduce the gap distance to less than one meter before breakdown will occur. With negative polarity tests, short gaps tend to reduce rise times below the required 50 – 250 microseconds, but the trend does not always hold for positive polarities.

Some explanation of the electric field is useful for understanding the common difficulties encountered with these tests. In particular, the fields at breakdown are not the same as the fields that would exist in the absence of pre-breakdown charge transport. For the negative polarity test, the gradient at the conductive tip of the test object is usually higher than the average gradient in the gap, so a negative leader forms there easily. Space charge then follows this leader toward the ground electrode, enhancing the electrode field until a positive leader is generated from ground shortly before the full channel forms. With the positive polarity test, it is still the case that negative leader formation is favored simply because of the high mobility of the negative charge carrier. Streamers and leaders may form most easily at edges of the test electrode, and may transport charge centers in directions other than toward the test object.

Changes in the electrode shape or distance may therefore be needed, and special care must be taken to avoid sharp corners or even small curvatures at the edge or backside of the electrode.

The Tesla coil is useful but not required. Not all labs have a Tesla coil, and in most cases simple visual inspection is sufficient to locate points of surface breakdown.



Figure 23.UG-3 - Positive Polarity with un-modified Electrode

23.UG.4.1.2.8 Data Interpretation

Post-test evaluation by the testing laboratory is usually limited to observations of attachment points and notes of any deviations from expected behaviour.

If no puncture occurs, then the high current test will be performed at a fastener or the nearest metallic surface of the test object.

23.UG.4.1.3 Swept Channel Attachment Test

23.UG.4.1.3.1 Test Purpose

This test is performed in order to determine the dielectric performance of a test object. Dielectrics can strongly affect the re-attachment of a lightning channel due to motion of an aircraft, which pulls the channel forward until the added inductance of the path forces the arc to a new, shorter path. In cases where the test object has no dielectric covering, then this test does not need to be performed.

23.UG.4.1.3.2 Test Object

The test object should be configured so that all fasteners and connections to ground are used to simulate an aircraft installation.

23.UG.4.1.3.3 Test Fixture

The test fixture should be constructed in such a way that the test object is mounted and all of the fasteners and connections to ground are used.

Other features of the installation may affect attachment. The test fixture should not include sharp edges that distort the electric fields in the vicinity of the test object, unless such features are needed to represent the intended aircraft installation. In most cases a simple ground plane that extends for several inches beyond the test object will be sufficient.

23.UG.4.1.3.4 Test Setup

Photographs of the calibrations should be taken. When the test is being performed, the camera should be positioned so that the sphere gap and the test electrode are both visible to determine which gap experienced breakdown. In cases where this is not possible, such as a very large test object, then a second camera should be used.

23.UG.4.1.3.5 Test Waveforms

Voltage waveform A is 1000 KV/uS or 1 MV/uS. With test levels between 70 and 280 KV and a time base of 100 ns/div, the rise time is equivalent to 100 KV/100 ns. The voltage for a swept channel attachment test is calculated to account for the longest sweep distance that might be expected for the aircraft on which the equipment will be installed. The voltage along a channel will increase because of the current rate of rise dI/dt , and the channel inductance $L(\text{channel})$. Assuming $dI/dt = 140 \text{ KA/microsecond}$ for the D waveform and $L(\text{channel}) = 1 \text{ micro Henry}$, the voltage will rise at 140 KV/m of sweep distance. The sweep distance itself can be as long as the fore/aft dimension of the equipment under test, but in practice the arc will seldom dwell longer than 20 mS before re-attaching to either the equipment or to some adjacent structure.

23.UG.4.1.3.6 Measurements and Data Recording

Photographs of each pulse are required which will show attachment to the test article or sphere gap breakdown.

23.UG.4.1.3.7 Test Procedure

Laboratory environmental conditions to measure and record should include temperature and humidity at the beginning of the test day, and preferably also at the end of the day, especially if there have been changes in weather. Very high or very low levels of humidity can have a significant effect on high voltage tests.

23.UG.4.1.3.8 Data Interpretation

The high current attachment location or locations are determined from the results of this test.

23.UG.4.2 High Current Physical Damage Testing

This test is like no other lightning test. The generators used to generate these waveforms are extremely dangerous and all safety precautions must be strictly followed while performing these tests. When fully charged, the generators will have an energy level in excess of one hundred thousand joules. Extreme caution must be exercised.

23.UG.4.2.1 High Current Test Waveform

The waveforms used for damage testing must provide a high amount of energy and charge transfer in a short time to simulate lightning effects. The waveforms include components that approximate the effects of the initial strike as well as continuing

current contributions. The initial strike and restrike are simulated with waveforms A or D, and the continuing currents by waveforms B and C*. Key characteristics of the waveforms include the peak current and the action integral (for A and D waveforms) and the duration; for the continuing current components B and C*, it is the average current and the total charge transfer.

Examples of acceptable high-current waveforms, taken from laboratory data acquisition systems, are shown in [Figure 23.UG-4](#) through [23.UG-15](#) below. Note that waveforms A and D may be oscillatory or unipolar, since the action integral is not sensitive to polarity. The B and C* are generally expected to be unipolar, since an integrating math function would give an erroneous result if it were to integrate total charge for a bipolar pulse. These are illustrations only; actual waveforms are allowed to take on other shapes provided they meet the key characteristics.

The timing of these waveforms can also be important, since in practice, it is difficult to perform ideal switching of a B or C* component at a precise zero crossing of the A or D component. Some laboratories fire the fast and slow components together, which can be done if inductive or diode isolation is provided. Delay circuits may also be used to control switching times. If the delay is too small, it is possible to damage high-voltage circuitry. If the delay is too large, the arc due to the initial waveform may extinguish and prevent firing of the continuing currents. Some experimentation with timing is to be expected, usually by adding or subtracting some tens of microseconds of delay.

When the three waveforms are applied simultaneously (which is recommended), the proper order is achieved in terms of peak current. The A or D component hits its peak first, followed by the B component and then the C or C* component.

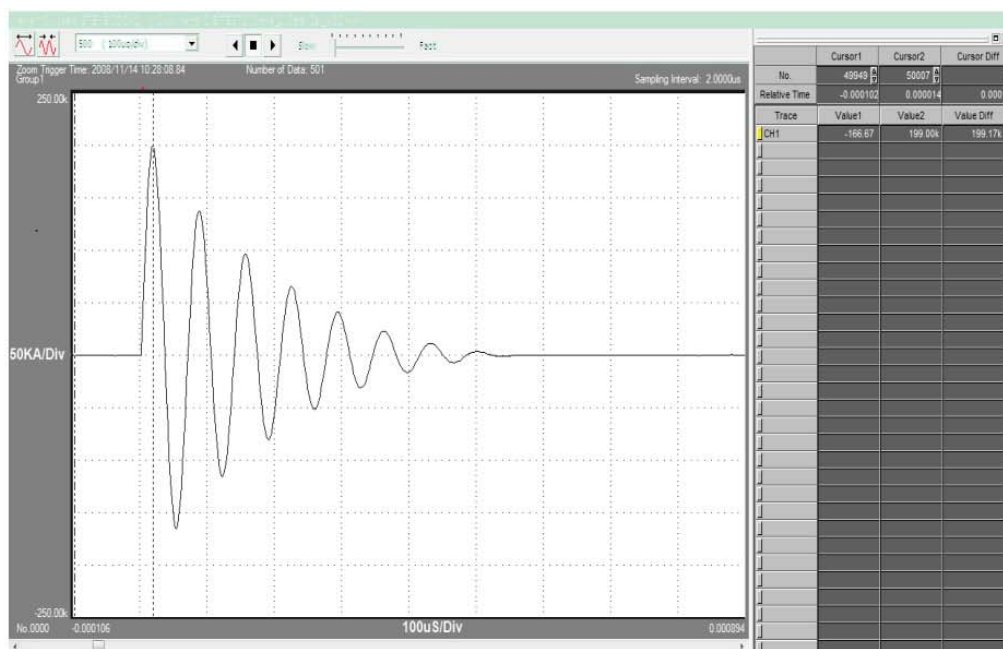


Figure 23.UG-4 - Typical Component A Oscillatory Current Waveforms

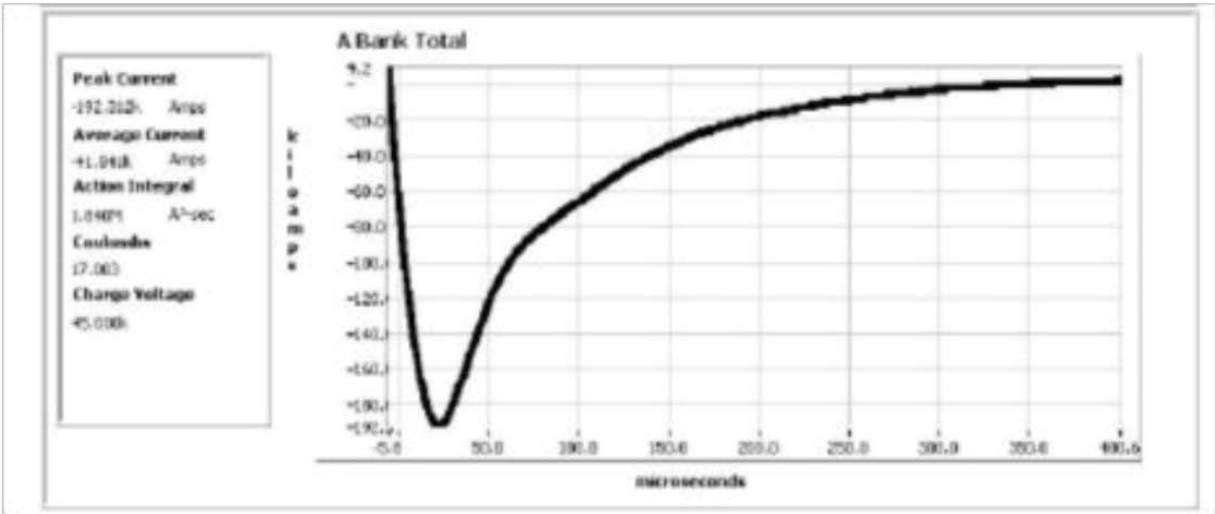


Figure 23.UG-5 - Typical Component A Unipolar Current Waveforms

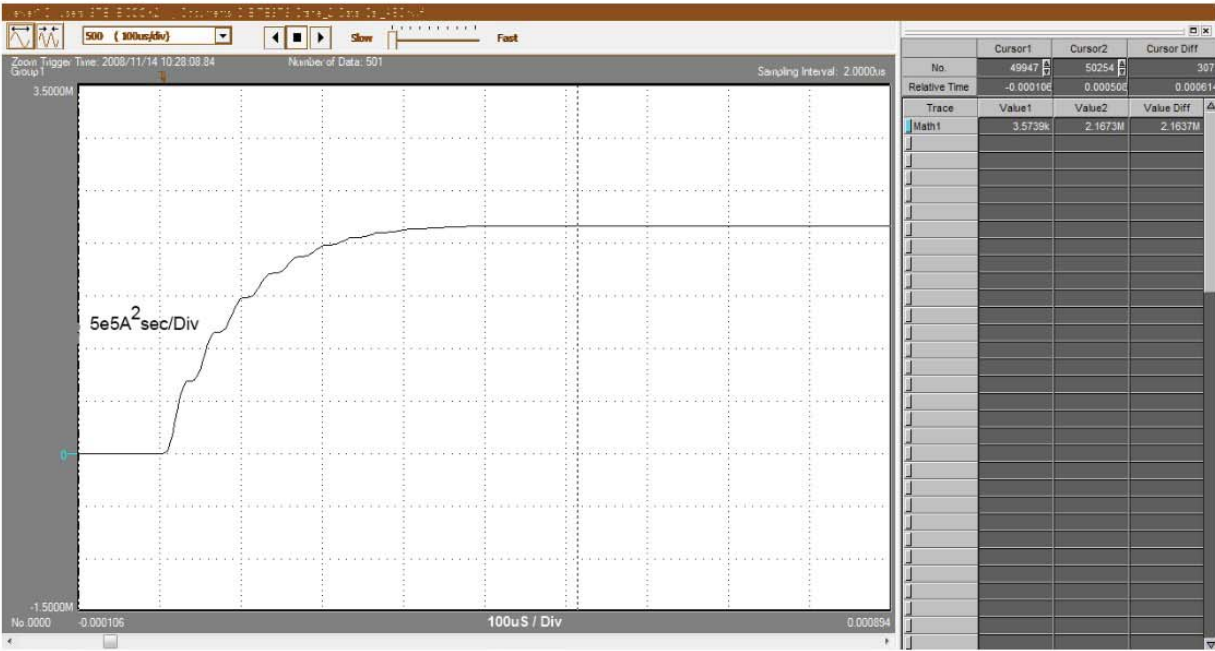


Figure 23.UG-6 - Typical Component A Action Integral

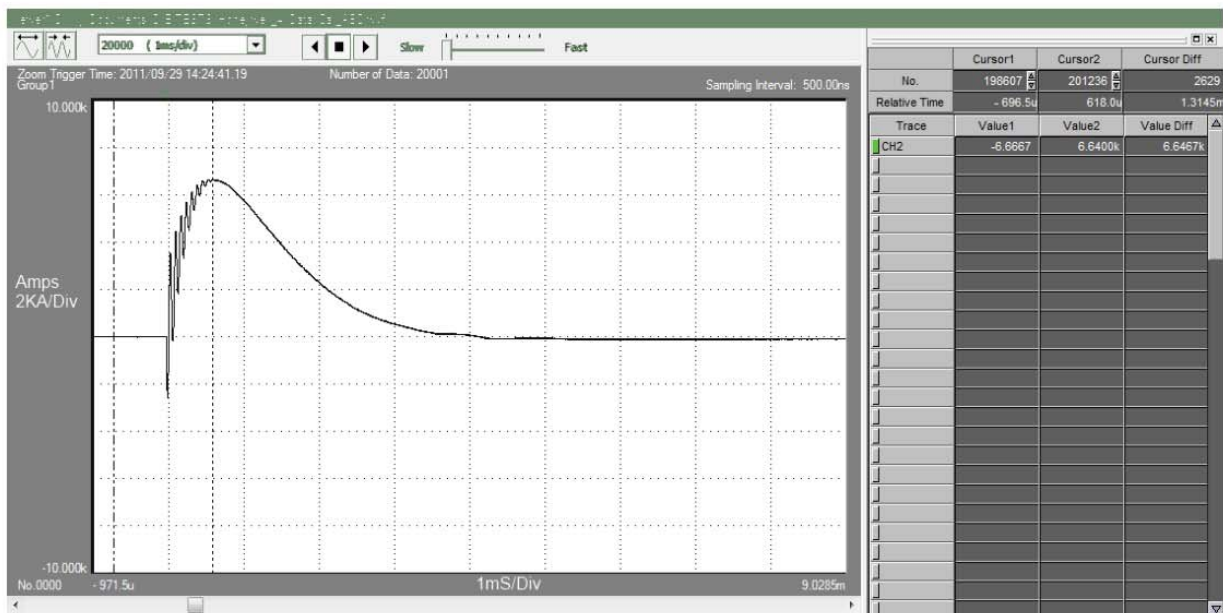


Figure 23.UG-7 - Typical Component B Current Waveform

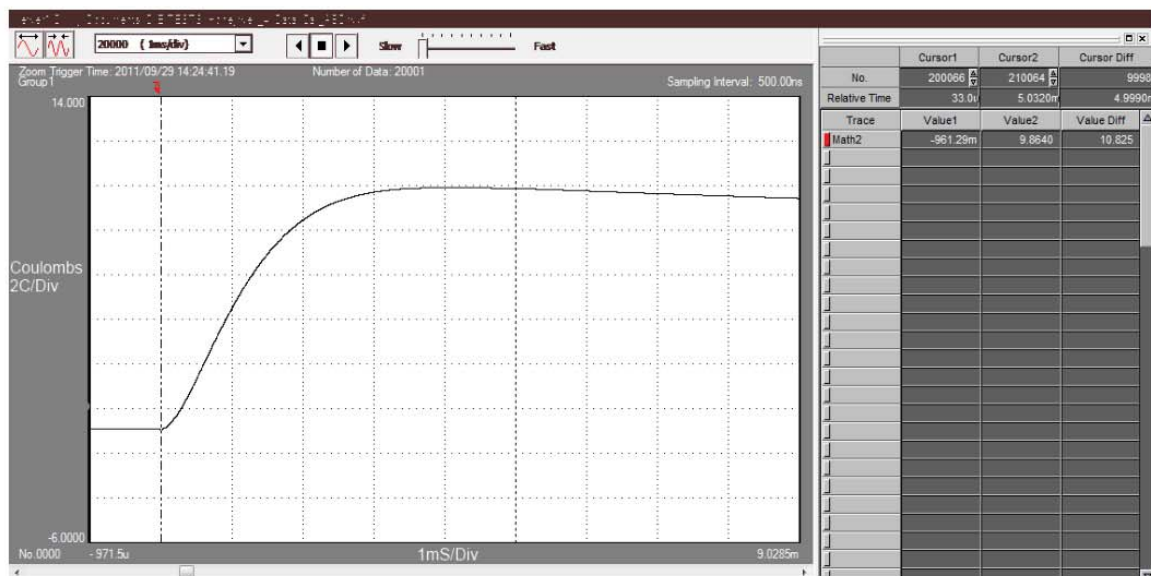


Figure 23.UG-8 Typical Component B Charge Transfer

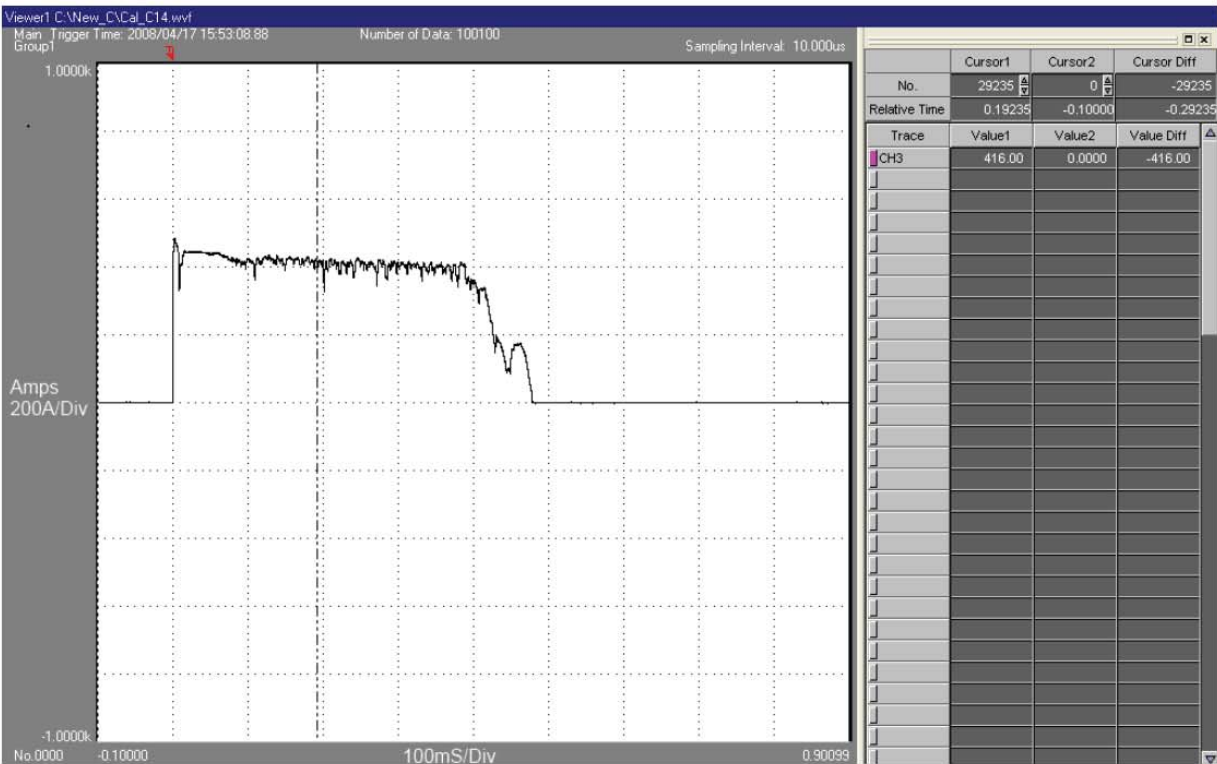


Figure 23.UG-9 - Typical Component C Current Waveform

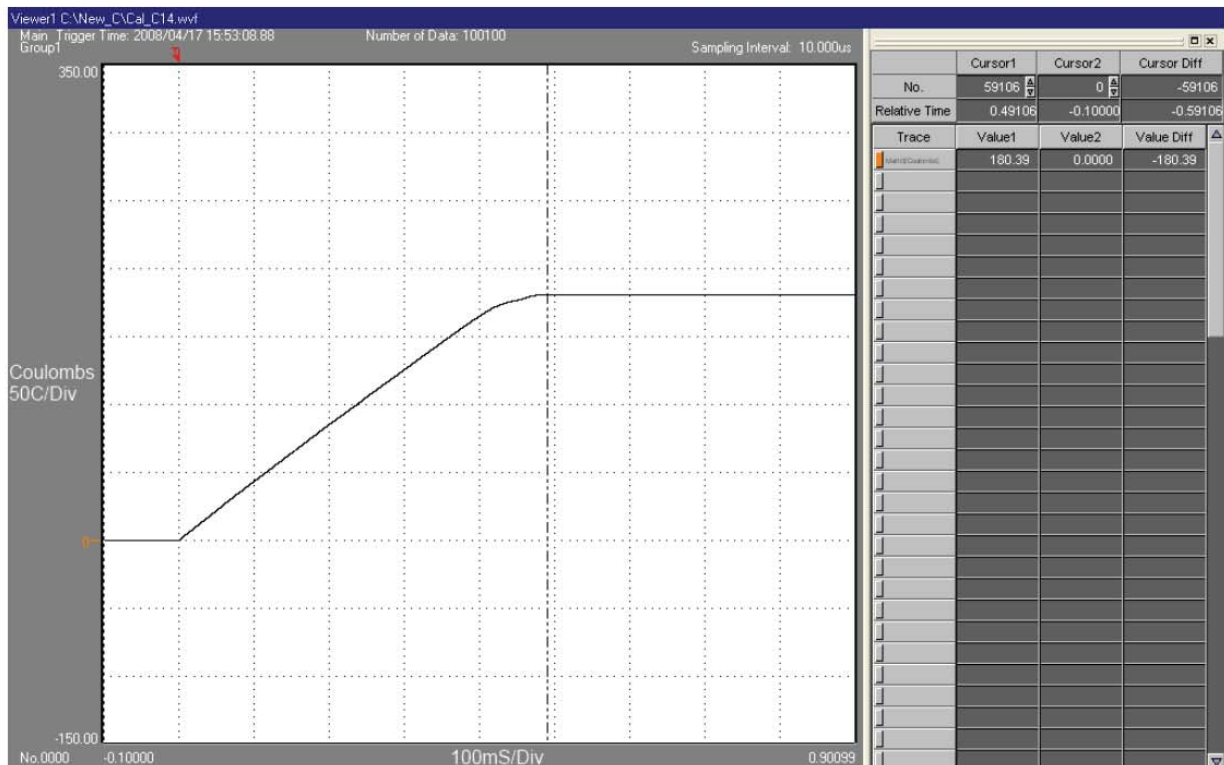


Figure 23.UG-10 - Typical Component C Charge Transfer

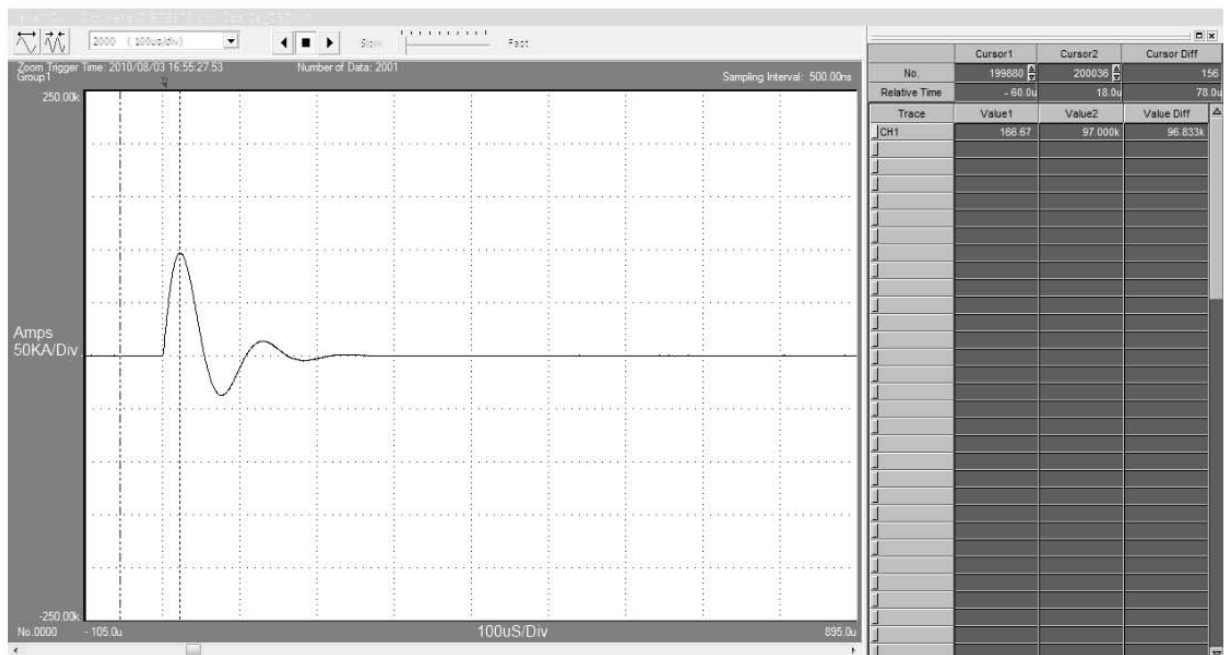


Figure 23.UG-11 - Typical Component D Oscillatory Current Waveforms

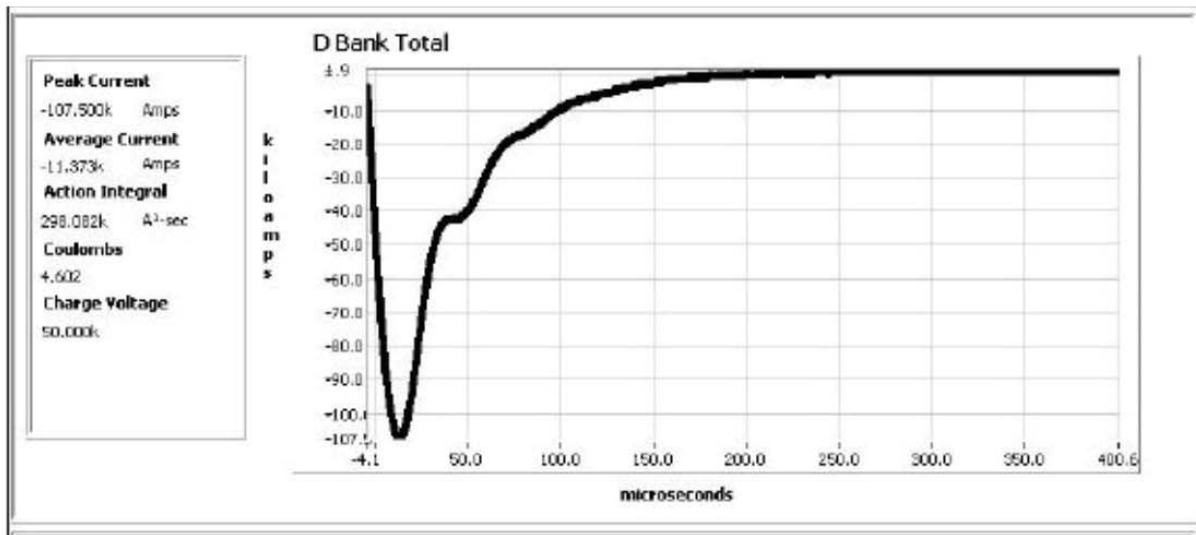


Figure 23.UG-12 - Typical Component D Unipolar Current Waveform

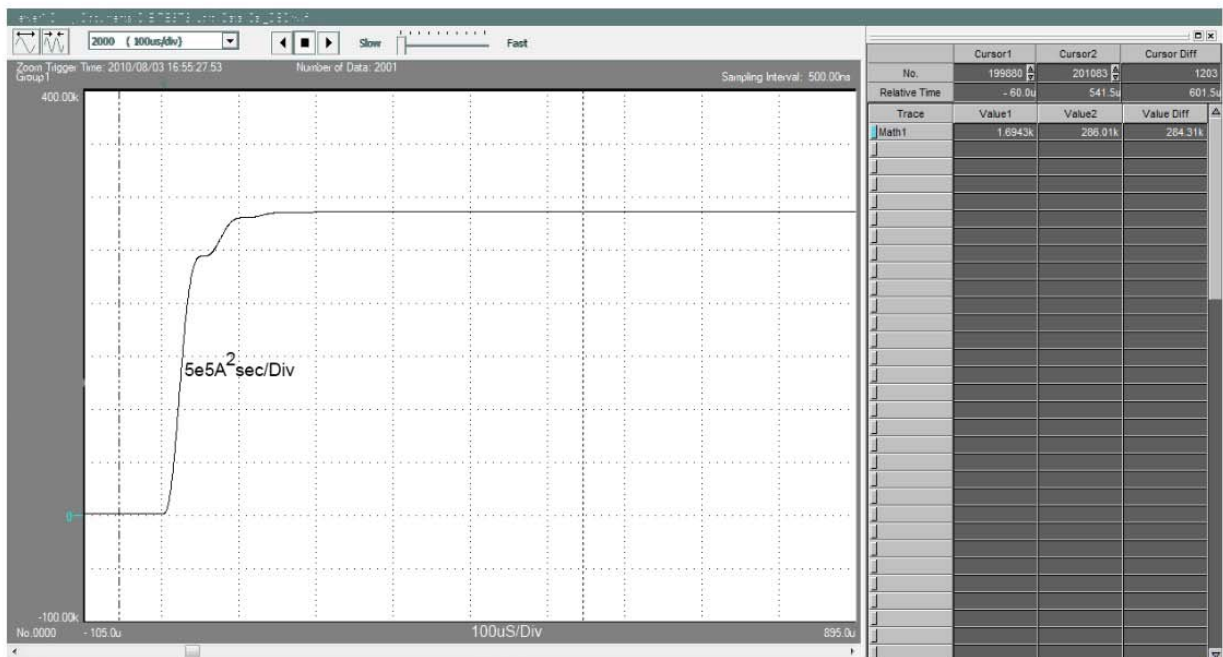


Figure 23.UG-13 - Typical Component D Action Integral

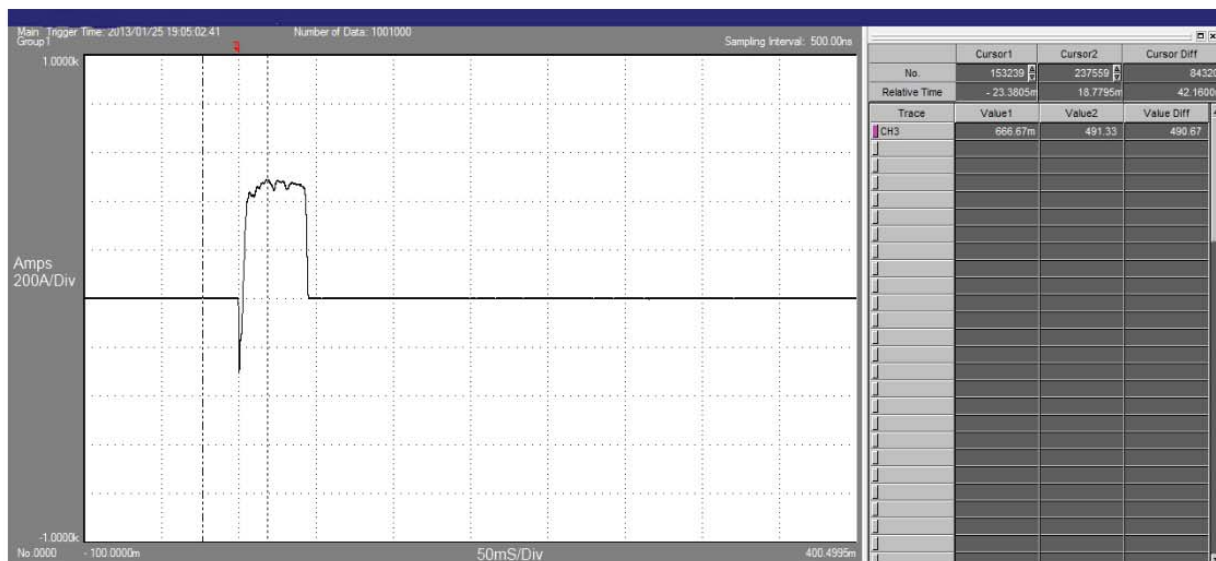


Figure 23.UG-14 - Typical Component C* Current Waveform

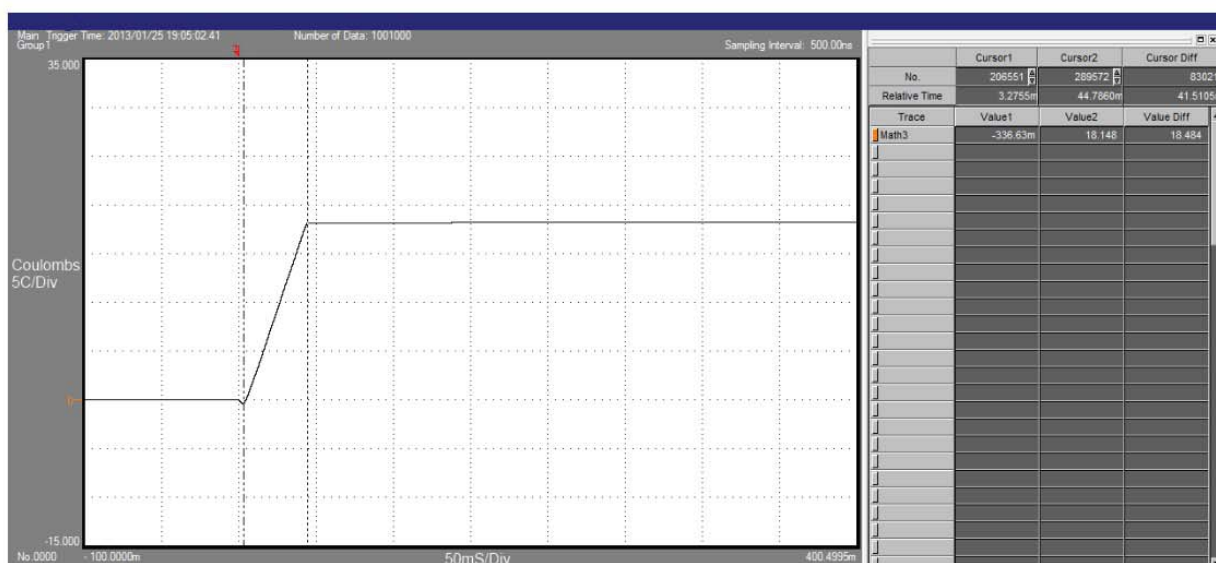


Figure 23.UG-15 - Typical Component C* Charge Transfer Waveform

23.UG.4.2.2 Arc Entry Test

23.UG.4.2.2.1 Test Purpose

In certain cases measurements of induced currents and voltages are not required, however if these measurements are required, then the procedures used in Section 23.4.3.3 should

be considered. These measurements are important for verification or determination of indirect effect test levels of the test object.

23.UG.4.2.2.2 Test Object

Considerations for different types of test objects

External Lights

- Test fixture size should be large enough to simulate aircraft installation.
- Induced measurements should be performed.

Antennas

- Test fixture size and material should simulate aircraft installation
- Induced measurements should be performed.

Fuel Filler Caps

- These must be tested with either of the spark detection methods specified in Section 23.4.3.2.

23.UG.4.2.2.3 Test Fixture

Test fixtures should be constructed such that the test object is mounted in a manner that simulates the actual aircraft installation. This includes connection points and aircraft material.

23.UG.4.2.2.4 Test Setup

There are two types of electrodes that can be used for this test – a solid copper electrode or a jet diverting electrode. When using the jet diverting electrode, it may be difficult to transfer a proper Component C* with the required parameters. The Component C* seems to transfer much better when using a solid copper electrode. This should be taken into consideration when performing tests which require this waveform.

23.UG.4.2.2.5 Test Waveforms

The test waveforms to be utilized are dependent on the aircraft zone in which the test object is located. This is due to the dwell time of an arc root at a given location as well as the phase of the lightning flash that is being expressed during that period of time.

23.UG.4.2.2.6 –Measurements and Data Recording

Photographs of the actual high current discharge are helpful in determining arc wandering or puncture of test objects.

The high current generator polarity should be configured for negative polarity when performing these tests.

23.UG.4.2.2.7 Test Procedure

Laboratory environmental conditions to measure and record should include temperature and humidity at the beginning of the test day, although these conditions are seldom as important for damage tests as for high voltage attachment tests.

In some cases the verification is more of a reference, depending on the test objects size and/or material. Sometimes the test object conductivity cannot be replicated or the

length of the current path of the test object will be such that the generators limitations will be reached.

23.UG.4.2.2.8 Data Interpretation

23.UG.4.3 Additional Test Requirements

23.UG.4.3.1 Externally Mounted Fuel Equipment

This section deals with spark detection techniques that will be used to determine whether ignition energies of 200 micro joules or greater are present.

23.UG.4.3.2 Methods for Detection of Ignition Sources

The two methods are photographic and ignitable mixture. Either method is acceptable and should be determined by the complexity of the test object. For engineering tests, it can be useful to employ both methods. However, in the case of a certification test, it is advised that only one method be used whether it is photographic or ignitable fuel mixture.

23.UG.4.3.2.1 Photographic method

23.UG.4.3.2.1.1 Test Purpose

This test uses cameras to detect ignition sources of 200 micro joules or greater when a high current test is applied to the test object.

23.UG.4.3.2.1.2 Test Equipment

The equipment used for this test will include enough cameras in order that the entire test object is in view. The test chamber will be light tight so that the cameras are able to detect any arcing or sparking.

23.UG.4.3.2.1.3 Test Procedure

Digital cameras, 35 mm film, and Polaroid film can be used in this method.

Historically, Polaroid black and white 3000ASA speed film (667) has been used to detect 200 μJ $\pm 10\%$ voltage sparks using an f/4.7 lens (without filters) no more than 1.5 m from potential ignition sources (including mirror reflection distance and losses).

When using digital, 35 mm, or Polaroid (instant film) camera, a demonstration should be made that verifies that the camera configuration can detect a 200 μJ $\pm 10\%$ voltage spark. The preferred method is to photograph a 200 μJ $\pm 10\%$ spark source in a light tight box with the camera up to 1 m away from the spark source. The camera settings used to detect the spark and the distance between the camera and the spark source should be documented so that the same settings are used during lightning testing. If any mirrors are to be used for the actual test, the same mirrors should be used in the calibration procedure to account for optical reflection losses. Effort should be taken to both focus the camera on the plane where ignition sources may occur and to have the potential ignition source location angle with respect to the camera be normal to the detection (sensor or film) plane. Deviation in angle from normal will reduce the sensitivity of the detection method.

For digital cameras, the camera model, lens model and settings, lens filters (if any), camera sensitivity (ISO equivalency), exposure times, digital file type (TIFF, JPEG, etc.), and any other camera setting that influences the resulting photograph should be recorded. When using a 35 mm or Instant film, the camera model, the lens model and settings, lens filters (if any), and film type should be recorded.

When using 35 mm film, the development process can affect the sensitivity of the printed 35 mm photograph. If fast development type film is used, the development time-temperature combination recommended by the manufacturer should be followed. Outdated film should not be used.

23.UG.4.3.2.1.4 Data Requirements

Whether light-on-film threshold determination is done by visual or software inspection, the same image format (JPEG, TIFF, RAW...) should be used for both the calibration and test evaluation. Care should be taken on which image format to be used and saved for archiving data. Different formats will produce various thresholds and image quality. Extra care should be taken with the use of JPEG format since with each consecutive resave, the JPEG routine is applied and data is lost.

23.UG.4.3.2.2 Ignitable Mixture (Flammable Gas) Test Method

23.UG.4.3.2.2.1 Test Purpose

This test can be used for any test object but must be used for test objects with complex geometry that will not allow complete views when using cameras. Using an ignitable test mixture is a more direct and finite determination of evaluating ignition hazard independent of what the potential ignition mechanism might be. The photographic method is an indirect method of evaluating ignition and various ignition mechanisms produce different amounts of visible light that may or may not have correlation to actual ignition threat.

23.UG.4.3.2.2.2 Test Equipment

The equipment for this test consists of an ignitable mixture gas chamber, and the 200 micro joule spark source.

Guidance suggests periodic cleaning and polishing of the electrode tips for reconditioning. This step should be done but with additional considerations. Most metals commonly used for arc electrodes form metal oxide layers with each arc. Metal oxides are a dielectric and tend to alter spark performance, breakdown voltage, and location on the electrode. Surface roughness also plays a role in spark performance, breakdown voltage, and location on the electrode. Sparker performance can be improved and made more consistent if the electrodes are conditioned by allowing the surface chemical composition and geometry to come to some equilibrium. This can be achieved by allowing the sparker to arc on the order of 3000-4000 times before use. If gapping tools such as feeler gauges are used, it is recommended that the gap is set prior to conditioning the electrodes via multiple arcs. Introducing a tool into the spark gap after the reconditioning step is taken, foreign metals may be deposited and surface roughness may be changed which nullify the conditioning effort. If sparker starts to perform erratically, it is recommended that the cleaning, polishing, and reconditioning steps are repeated. It is also recommended that prior to executing actual tests, the sparker should be turned on and allowed to arc. When tests are performed after the sparker has been “warmed up” via multiple arcs, the breakdown voltage and energy during the test will be predictable. Ensuring the sparker components and body surfaces are clean and dry (conditioned in atmosphere less than 10% relative humidity) will improve predictable sparker performance. Humidity, dielectric surface water absorption, and oily components promote charge leakage paths that create a parallel resistance with the arc gap which reduces the actual voltage drop across the electrodes and reduces the actual energy of the arc as well as reduces predictability.

23.UG.4.3.2.2.3 Test Procedure

This test may be performed with any fuel mixture that meets the statistical intent of 90% probability of detecting a 200 μ J voltage arc source. The fuel mixture should be adjusted to be able to detect a potential ignition source but not too sensitive such that additional unquantified and unintentional conservatism is added. When using the prescribed fuel mixture ratios, the lower H₂ percentage will bring the minimum ignition energy of the gas mixture closer to 200 μ J which will minimize the sensitivity of the mixture. It should be understood that the gas sensitivity is a function of the minimum ignition energy of the H₂ percentage and will be lower than the 180 micro joule low end tolerance for the spark source ignition.

It has been shown that a fuel mixture based on “air” (79% nitrogen, 21% oxygen) provides some advantages in this test method. A fuel in air environment is more reliable and induces potential ignition sources in a more realistic way. The use of argon as a diluent has shown to cause premature breakdown or streamering in ways realistic breakdown in air will not occur. The optical output of ignition sources also change in an argon environment vs nitrogen based air. In addition, using air simplifies the calibration steps since cameras and controlled energy spark sources can be calibrated in open air rather than in the artificial argon based environment recommended.

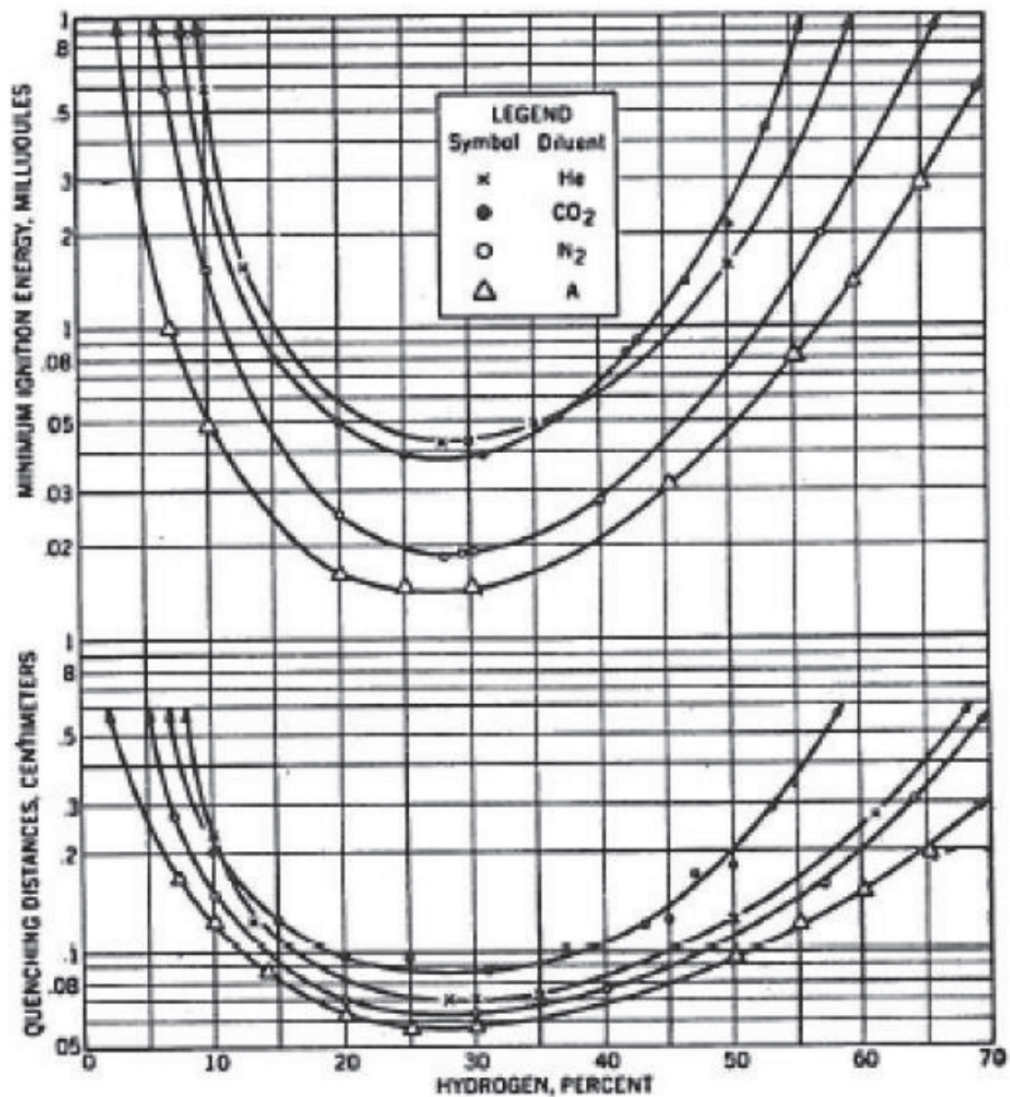


Figure 23.UG-16 - Minimum Ignition Energy Curve

23.UG.4.3.2.2.4 Data Requirements

The ignition energies from the chamber calibration as well as the tests that are performed need to be recorded.

Gas mixture flow rate data can be helpful in determining the average H₂ percentage of the mixture.

23.UG.4.3.3 Measurement of Induced Voltage in External Hardware

23.UG.4.3.3.1 Test Purpose

Induced voltages and currents are an important aspect of direct effects testing and the necessity of these measurements must be determined on a case by case basis. These measurements are normally performed during high current testing. The data obtained from these measurements will assist in determining or verifying the indirect effect transient levels for that particular test object.

23.UG.4.3.3.2 Test Object

Test objects that should be considered for induced signal measurements may include but are not limited to antennas, actuators, lights, windshields and air data probes.

23.UG.4.3.3.3 Test Fixture

Any test object cabling should be configured to replicate the aircraft installation and should be long enough to exit the high current test area. This is especially important for voltage measurements in order to reduce any noise from the high current discharge.

23.UG.4.3.3.4 Test Setup

23.UG.4.3.3.5 Measurement and Data Recording

Power line transients are particularly important and voltage and/or current measurements should be considered on any test object connected to the power buss. Currents on shielded interconnecting cables should also be taken into consideration.

23.UG.4.3.3.6 Test Procedure

Laboratory environmental conditions to measure and record should include temperature and humidity at the beginning of the test day, although these conditions are seldom as important for induced voltage tests as for high voltage attachment tests.

23.UG.4.3.3.7 Data Interpretation

The data obtained from these measurements will be used to determine the test levels for the indirect effects lightning tests as well as verify that the indirect effect levels for a particular test object are sufficient.

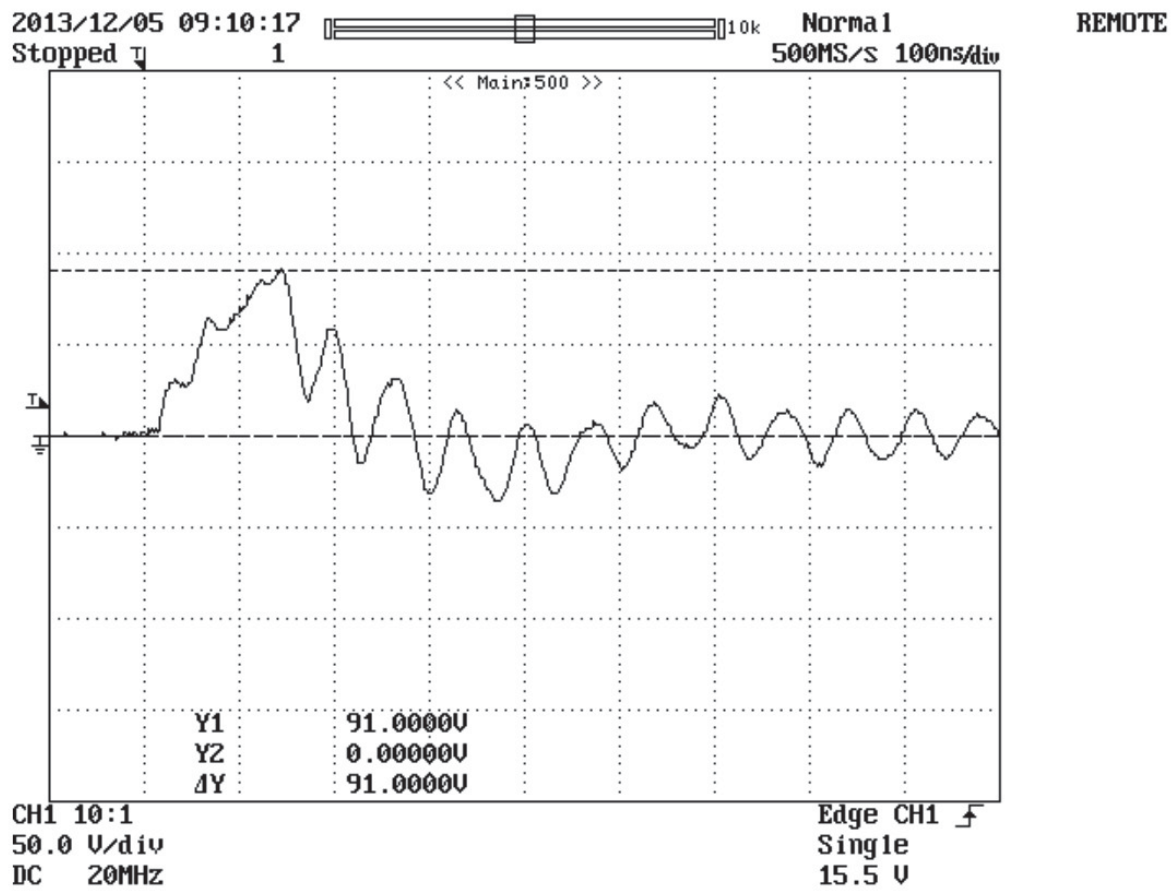


Figure 23.UG-17 - Voltage Waveform A – 50 KV/Div.

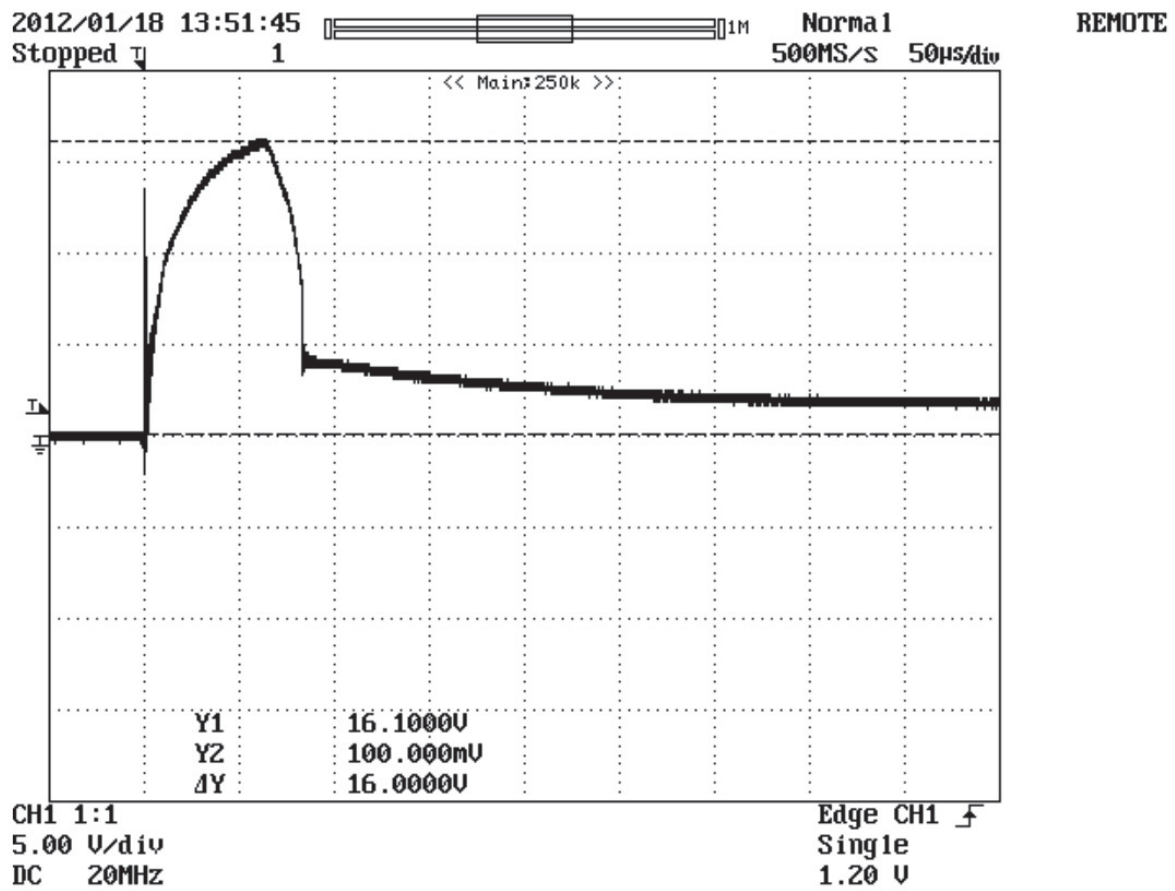


Figure 23.UG-18 - Voltage Waveform D – 500 KV/Div.

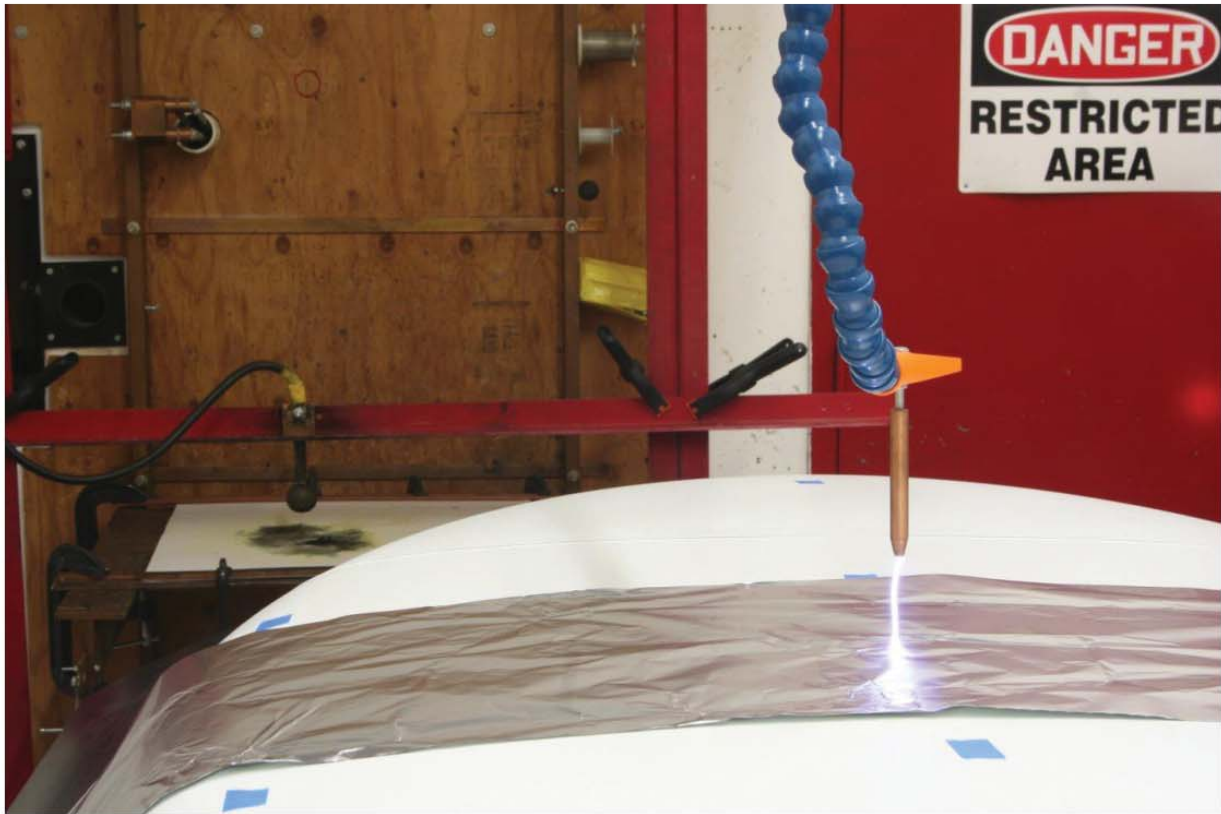


Figure 23.UG-19 - Test Electrode for Swept Channel Attachment Test

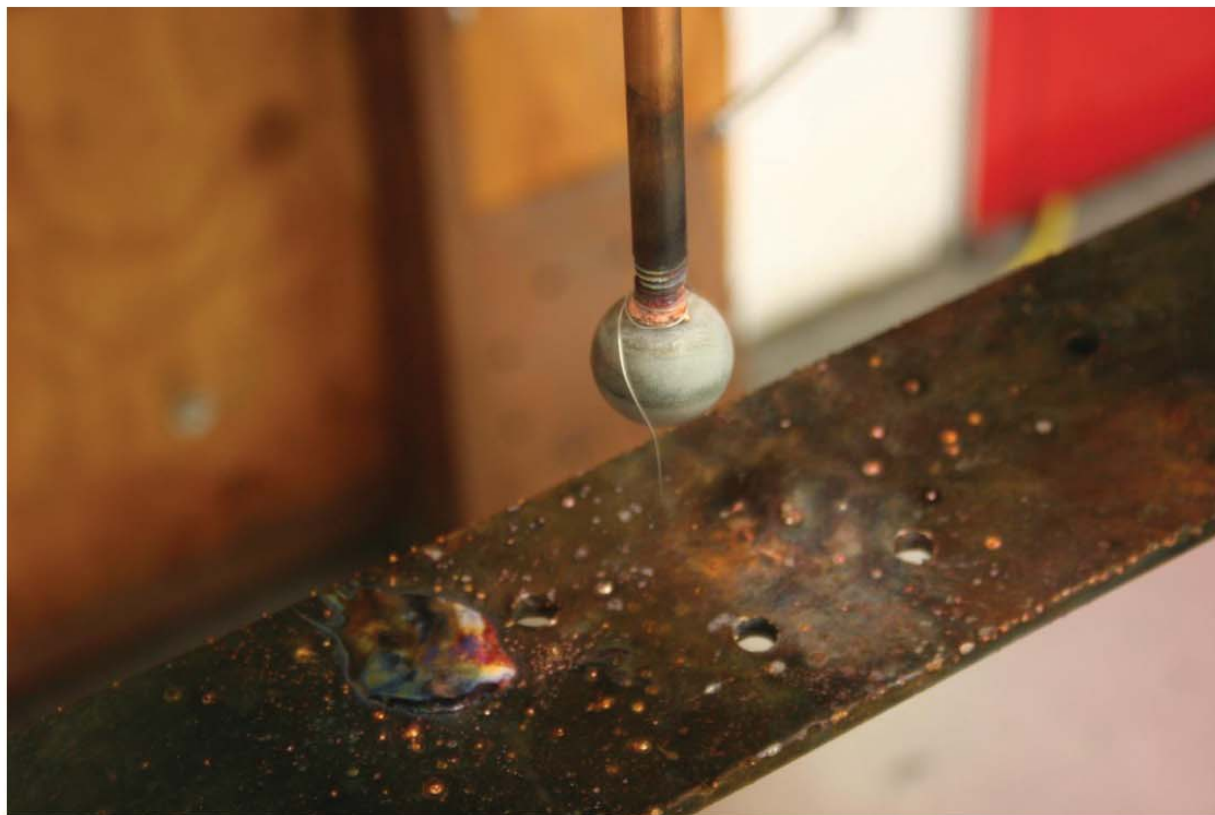


Figure 23.UG-20 - Typical Jet Diverting Test Electrodes

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DO-160G

**Environmental Conditions and Test Procedures
for Airborne Equipment**

User Guide for Section 26

Fire, Flammability

**Based on
DO-160G Section 26**

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There are numerous accepted fire test specifications and Advisory Circulars for conducting fire testing of components in designated fire zones. Some of these specifications are very specific for testing a particular component such as a hose conveying flammable fluid which may include a bend in the hose (in the fire area) as well as vibration on the product during application of the flame. Others are more generic and intended for all components in designated fire zones which may include gearbox accessories, firewalls, valves, etc. Because of the number of different specifications (accepted methods) and the variability of each, the test method presented in this section is intended as a guide, a test plan should be tailored to meet your approval agency.

26.UG.4.1 Apparatus**26.UG.4.2 Burner Calibration****26.UG.4.3 Flame Temperature**

Advisory Circular AC No: 33.17-1 states: “The capability of a part or component to withstand, as well as or better than steel, a **2000°F average flame temperature (± 150°F individual thermocouple tolerance)**”. This statement implies that the average temperature taken over the course of the calibration period shall have a minimum reading of 2000°F.

Figure 26-15 of DO-160G shows the burner in a horizontal configuration. The thermocouple rake is positioned 4 inches from the end of the burner extension cone and 1 inch above the centerline (due to flame buoyancy). If the burner is positioned in a vertical configuration the thermocouple rake shall be positioned on the centerline of the extension cone. This applies to the copper tube (flame intensity calibration device) placement as well.

26.UG.4.4 Flame Intensity**26.UG.4.5 Steady State Operating Conditions**

26.UG.4.6 Flame Direction and Location(s) Determination**26.UG.4.7 Fire Proof Test****26.UG.5 Fire Resistance Test****26.UG.5.1 Data Recording****26.UG.6 Flammability Test****26.UG.6.1 Determination of Type of Test****26.UG.6.2 Vertical Bunsen Burner Test for Cabin and Cargo Compartment Materials**

This supplement contains advisory material pertinent to referenced paragraphs. This test method is intended for use in determining the resistance of materials to flame when tested according to 12-second Vertical Bunsen Burner Tests specified in Federal Aviation Regulation (FAR) 25.853 and FAR 25.855. There is also a 60 second vertical test that is intended to show compliance for interior compartments occupied by crew or passengers. This method was not included because the intent of this 60 second test is for testing interior ceiling panels, interior wall panels, partitions, galley structure, large cabinet walls, structural flooring, and materials used in the construction of stowage compartments. As stated in paragraph 26.6.2.3, the methods to show compliance to category C are for enclosures housing electronics and non-metallic material, component parts, sub-assemblies installed in pressurized or non-pressurized zones and non-fire zones.

26.UG.6.2.1 Definitions**26.UG.6.2.1.1 Ignition Time**

Ignition time should start only after the flame has stabilized and is properly positioned under the test specimen.

26.UG.6.2.1.2 Flame Time**26.UG.6.2.1.3 Drip Flame Time****26.UG.6.2.1.4 Burn Length**

This definition of burn length is a clarification of that used in FAR 25, Appendix F, Part I, viz.: “Burn length is the distance from the original edge to the farthest evidence of damage to the test specimen due to flame impingement including areas of partial or complete consumption, charring, or embrittlement, but not including areas sooted, stained, warped, or discolored nor areas where material has shrunk or melted away from the heat source.” The main point is that “damage to the test specimen due to flame impingement” is clarified by “damage to the test specimen due to that area’s combustion” because it is a better description of the intent of the rule and is consistent with current test practices.

The burn length definition specified in FAR 25, Appendix F, applies to all materials listed in Part 25.853 and FAR 25.855. Since such a wide variety of materials require vertical Bunsen burner testing, areas that might obviously be included as burn length in some materials may not always be as well defined in others.

For the most part, these materials may be divided into four general categories; they are polymeric materials (such as panels, partitions, transparencies, etc., which may be hybrid or single plastic material), textiles, carpeting, and foams.

The following methods have been suggested for determining burn length:

- a. **Polymeric Materials.** In order to fix the boundary where the flame front was impinging on the specimen surface and damaging the specimen due to that area's combustion, i.e., below which combustion of the specimen occurred and above which it did not, it is necessary to observe the specimen continuously during the test. Flame impingement on the specimen may lead to outgassing due to thermal decomposition. As these gases burn, radiating heat may cause discoloration, sooting, staining, melting, etc., to areas above the flame front. This type of damage is not a result of thermal decomposition due to flaming and, therefore, would not be included in the burn length.
- b. **Polyurethane Foams.** Polyurethane foams are cellular in nature and, therefore, have low thermal conductivity. Since high surface temperatures are generated on exposure to the burner flame, an almost instantaneous conversion to flammable gases results. This, in turn, produces rapid surface flame spread with complete consumption of the foam immediately above the ignition source. By definition, complete consumption of an area is part of the burn length and should be included.

26.UG.6.2.2 Apparatus

26.UG.6.2.2.1 Test Cabinet

Suitable test cabinets of the type described are manufactured by the U.S. Testing Co., 1415 Park Ave., Hoboken, New Jersey 07030; Atlas Electric Devices Co., 4114 N. Ravenswood Ave., Chicago, Illinois 60613; and The Govmark Organization, Inc., P.O. Box 807, Bellmore, New York 11710.

Draft free implies a condition of no air currents in a closed in space. One way of determining whether the cabinet is draft free is to place a smoldering and smoking material, such as a lighted cigarette, in the test cabinet, then closing the door and observing the behavior of the smoke for signs of drafts. A test cabinet other than one fabricated in accordance with Figure 26-1 to Figure 26-2 may be found to be acceptable after review by the FAA.

The entire inside back wall of the chamber may be painted flat black to facilitate viewing of the test specimen, and a mirror may be located on the inside back surface to facilitate observation of the hidden surfaces.

26.UG.6.2.2.2 Specimen Holder

26.UG.6.2.2.3 Burner

A suitable burner is available from Rascher & Betzold Inc., 5410 N. Damen Ave., Chicago, Illinois 60625, Catalog No. R3726A.

26.UG.6.2.2.3.1 Burner Fuel

26.UG.6.2.2.3.2 Plumbing for Gas Supply

26.UG.6.2.2.3.3 Flame Height Indicator

The tip of the methane flame is blue, transparent, and difficult to see. It is more easily seen if there is no light on the flame, as in a darkened room. The inner cone of the flame is, however, more visible and easily seen and can be used to monitor flame height. When the flame height (blue transparent tip) is set to 1.5 inches, the height of the inner cone has been found to vary slightly from burner to burner, but is generally about 7/8 inch. Therefore, if the inner cone height is used to monitor flame height, the inner cone height needs to be established for that burner.

26.UG.6.2.2.3.4 Timer

26.UG.6.2.2.3.5 Ruler

26.UG.6.2.3 Test Specimens

26.UG.6.2.3.1 Specimen Selection

26.UG.6.2.3.2 Specimen number

26.UG.6.2.3.3 Specimen Size

By regulation, there must be at least 2 inches of the specimen exposed; however, the text specifies a specimen cut 3 inches in width. This allows enough material to ensure that the specimen is securely held in the holder. From experience, it has been found that materials such as films are difficult to secure in the holder and, therefore, may be cut even greater than 3 inches in width. This allows the operator adequate material to pull or adjust so that the specimen does not buckle or fall out of the holder.

26.UG.6.2.3.4 Specimen Thickness

According to the FAR 25.853, the specimen thickness must be no thicker than the minimum thickness to be qualified for use in the airplane. If the test facility has found

from experience or has questions concerning the flammability of a thicker specimen, then vertical testing may be conducted and test data recorded for further review.

26.UG.6.2.4 Conditioning

As stated in the FAR 25.853, only one specimen may be removed at a time from the conditioning chamber prior to being subjected to the flame. Some facilities, however, have conditioning chambers located in areas remote from the testing area. In this case, it is permissible to remove more than one specimen at a time only if each specimen is placed in a closed container (a plastic stowage bag is acceptable) and protected from contamination such as dirty lab tops, soot in the air, etc., until the specimen is subjected to the flame.

26.UG.6.2.5 Procedure

26.UG.6.2.5.1 Burner Adjustment

26.UG.6.2.6 Test Procedure

- 1)
- 2)
- 3)
- 4) More information is available in DOT/FAA/CT-86/22, “An Investigation of the FAA Vertical Bunsen Burner Flammability Test Method.” Appendix F, FAR 25.853, Part I describes this test and specifies that the flame be placed “along the centerline of the lower edge.” The “centerline of the lower edge” is the line from the front face to the back face of the specimen. For thicker specimens, this is ambiguous since exactly “where” along the “centerline of the lower edge” is not specified.

Historically, test practices regarding burner flame placement have not been uniform or consistent within either the FAA or aircraft manufacturers. The most common placement used in the past was specified in the original issue of this handbook, viz.:

For specimens that are 3/4 inch (19 mm) thick or less, place the burner barrel centerline under the center of the bottom surface of the specimen.

For specimens thicker than 3/4 inch (19 mm), center the burner barrel under the bottom surface of the specimen 3/8 inch (10 mm) in from the surface exposed to the airplane interior, test each surface separately unless the surfaces are of the same materials and construction.

Another placement that has been less commonly used is that specified here, viz., directly under the middle of the lower edge of the face of the specimen that is exposed to the airplane interior. For specimens thinner than the burner barrel thickness (3/8 inch; 10 mm), test results are relatively insensitive to exactly where “along the centerline of the lower edge” the burner flame is placed. For samples of greater thickness, however, burn lengths are typically an inch or so longer if the burner barrel centerline is placed under or near the specimen face, and flame times

are sometimes a little longer than if the flame is placed per the original handbook, Report DOT/FAA/CT-89/15, September 1990.

Materials used in contemporary (especially post heat release) designs produce burn lengths and flame times that are considerably less than the acceptance criteria for certification (6 inches and 15 seconds), regardless of where the flame is placed. Although where the burner flame is applied is not of important pass/fail significance in this test, placing it directly under the specimen face generally represents a worst-case situation.

The FAA should accept data for certification using the flame placement described in the original portion of this handbook, or using the flame placed under the exposed face of the test specimen. However, the FAA and aircraft manufacturers have agreed that in the future, the preferred placement of the burner flame is under the middle of the lower edge of the face of the specimen.

- 5) If the burner extinguishes during the ignition time for any reason, rerun the test. From experience, it has been found that this is a necessary requirement when running a 12-second test. The opposite end of the same specimen can be used for the retest if the burn length for the aborted test is less than 3 inches (76 mm). If the burn length for the aborted test is greater than 3 inches (76 mm), a new specimen must be used.
- 6)
- 7)
- 8) The operator should refer to the facility's safety manual for further information on dealing with smoke and flammability by-products.
- 9)
- 10)

26.UG.6.2.7 Report

26.UG.6.2.7.1 Material Identification

26.UG.6.2.7.2 Test Results

26.UG.6.2.8 Requirements

26.UG.6.2.8.1 Flame Time

26.UG.6.2.8.2 Drip Flame Time

26.UG.6.2.8.3 Burn Length

26.UG.6.3 Horizontal Bunsen Burner Test for Miscellaneous Materials

26.UG.6.3.1 Definitions**26.UG.6.3.1.1 Ignition Time**

Ignition time should start only after the flame has stabilized and is properly positioned under the test specimen.

26.UG.6.3.1.2 Burn Rate**26.UG.6.3.2 Apparatus****26.UG.6.3.2.1 Test Cabinet**

Suitable test cabinets of the type described are manufactured by the U.S. Testing Co., 1415 Park Ave., Hoboken, New Jersey 07030; Atlas Electric Devices Co., 4114 N. Ravenswood Ave., Chicago, Illinois 60613; and The Govmark Organization, Inc., P.O. Box 807, Bellmore, New York 11710.

Draft free implies a condition of no air currents in a closed in space. One way of determining whether the cabinet is draft free is to place a smoldering and smoking material, such as a lighted cigarette, in the test cabinet, then closing the door and observing the behavior of the smoke for signs of drafts. A test cabinet other than one fabricated in accordance with Figure 26-6 to Figure 26-8 may be found to be acceptable after review by the FAA.

The entire inside back wall of the chamber may be painted flat black to facilitate viewing of the test specimen, and a mirror may be located on the inside back surface to facilitate observation of the hidden surfaces.

26.UG.6.3.2.2 Specimen Holder**26.UG.6.3.2.3 Burner**

A suitable burner is available from Rascher & Betzold, Inc., 5410 N. Damen Ave., Chicago, Illinois 60625, Catalog No. R3726A.

26.UG.6.3.2.4 Burner Fuel**26.UG.6.3.2.5 Plumbing for Gas Supply****26.UG.6.3.2.6 Flame Height Indicator**

The tip of the methane flame is blue, transparent, and difficult to see. It is more easily seen if there is no light on the flame, as in a darkened room. The inner cone of the flame is, however, more visible and easily seen.

26.UG.6.3.3 Time**26.UG.6.3.4 Ruler****26.UG.6.3.5 Test Specimens****26.UG.6.3.5.1 Specimen Selection****26.UG.6.3.5.2 Specimen number****26.UG.6.3.5.3 Specimen Size**

A 3-inch by 13-inch (76- by 330-mm) specimen can be used to secure the specimen at the end of the specimen holder.

26.UG.6.3.5.4 Specimen Thickness

According to the FAR 25.853, the specimen thickness must be no thicker than the minimum thickness to be qualified for use in the aircraft. If the test facility has found from experience or has questions concerning the flammability of a thicker specimen, then vertical testing may be conducted and test data recorded for further review.

26.UG.6.3.5.5 Specimen Preparation**26.UG.6.3.6 Conditioning**

As stated in the FAR 25.853, only one specimen may be removed at a time from the conditioning chamber prior to being subjected to the flame. Some facilities, however, have conditioning chambers located in areas remote from the testing area. In this case, it is permissible to remove more than one specimen at a time only if each specimen is placed in a closed container (a plastic stowage bag is acceptable) and protected from contamination such as dirty lab tops, soot in the air, etc., until the specimen is subjected to the flame.

26.UG.6.3.7 Procedure**26.UG.6.3.7.1 Burner Adjustment**

- 1)
- 2)
- 3)
- 4) It is important to note that the test should be watched carefully while it is being conducted. This applies to all samples.
- 5)
- 6) Some laboratories turn the gas off upon completion of the test; however, the majority of test facilities, including the OEMs, withdraw the flame by moving the burner away from the specimen.
- 7)
- 8) The operator should refer to the facility's safety manual for further information dealing with smoke and flammability by-products.
- 9)
- 10)

26.UG.6.3.8 Test Results - Burn Rate**26.UG.6.3.9 Report****26.UG.6.3.9.1 Material Identification****26.UG.6.3.9.2 Test Results****26.UG.6.3.10 Requirements****26.UG.6.3.10.1 Burn Rate****26.UG.6.4 60-Degree Bunsen Burner Test for Electric Wire****26.UG.6.4.1 Definitions****26.UG.6.4.1.1 Ignition Time**

Ignition time should start only after the flame has stabilized and is properly positioned under the test specimen.

26.UG.6.4.1.2 Flame Time**26.UG.6.4.1.3 Drip Flame Time****26.UG.6.4.1.4 Burn Length****26.UG.6.4.2 Apparatus****26.UG.6.4.2.1 Test Enclosure and Setup**

Draft free implies a condition of no air currents in a closed in space. One way of determining whether the cabinet is draft free is to place a smoldering and smoking material, such as a lighted cigarette, in the test cabinet, then closing the door and observing the behavior of the smoke for signs of drafts. A test cabinet other than one described in section 26.6.4.2.1 may be found to be acceptable after review by the FAA.

The entire inside back wall of the chamber may be painted flat black to facilitate viewing of the test specimen, and a mirror may be located on the inside back surface to facilitate observation of the hidden surfaces.

26.UG.6.4.2.2 Specimen Holder**26.UG.6.4.2.2.1 Clamp and Pulley****26.UG.6.4.2.2.2 Weight****26.UG.6.4.2.3 Burner**

A suitable burner is available from Rascher & Betzold, Inc., 5410 N. Damen Ave., Chicago, Illinois 60625, Catalog No. R3726A.

26.UG.6.4.2.3.1 Burner Fuel

Gases such as natural gas and propane can be used as burner fuel. However, it should be required to show compliance with the 1750°F minimum flame temperature using a 24 AWG thermocouple.

26.UG.6.4.2.3.2 Plumbing for Gas supply**26.UG.6.4.2.3.3 Flame Height Indicator****26.UG.6.4.2.4 Timer****26.UG.6.4.2.5 Ruler****26.UG.6.4.3 Test Specimens****26.UG.6.4.3.1 Specimen Number****26.UG.6.4.3.2 Specimen Length**

It is strongly recommended to have samples length of 30 inches. However, in the event that 30 inches of product is not available, actual length of test item may be used and additional non-flammable cable can be attached to item (metal clip or similar) to complete tension using pulley. In addition, the actual specimen length should be long enough to be able to demonstrate compliance to the < 3 inches burn length requirement.

26.UG.6.4.3.3 Specimen Preparation**26.UG.6.4.4 Conditioning**

As stated in FAR 25.853, only one specimen may be removed at a time from the conditioning chamber prior to being subjected to the flame. Some facilities, however, have conditioning chambers located in areas remote from the testing area. In this case, it is permissible to remove more than one specimen at a time only if each specimen is placed in a closed container (a plastic stowage bag is acceptable) and protected from contamination such as dirty lab tops, soot in the air, etc., until the specimen is subjected to the flame.

26.UG.6.4.5 Procedure**26.UG.6.5.1 Burner Adjustment**

- 1)
- 2)
- 3)
- 4) Alternative Burner Placement

Place the burner into position so that the top end of the burner barrel is 1 inch from the mark on the specimen. Make sure the centerline of the burner barrel is perpendicular to the underside of the mark on the specimen, that the centerline of the burner barrel forms an angle of 30 degrees with the line that is in the vertical plane containing both ends of the specimen, is perpendicular to the specimen, and passes

through the mark on the specimen. It has been found convenient to fabricate a fixture to position and hold the location of the burner quickly and repeatably (see Figure 26.A-1).

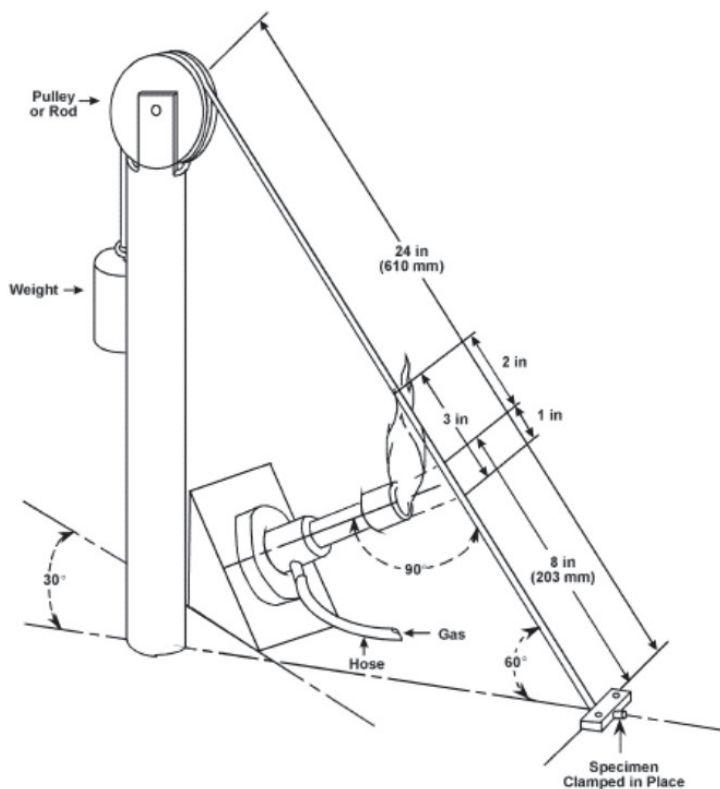


Figure 26.UG-1: Alternative Setup for 60-Degree Electrical Wire Bunsen Burner Test

26.UG.6.5.2 Test Procedure

- 1)
- 2)
- 3)
- 4)
- 5)
- 6) The operator should refer to the facility's safety manual for further information dealing with smoke and flammability by-products.

NOTE: The Alternative Burner Placement conforms to the 30-second, 60-degree Bunsen burner test described in FAR 25, Appendix F, Part I through Amendment 25-72. The FAA William J. Hughes Technical Center has determined that the Burner Placement in section 26.6.4.5.1, Item 4) produces equivalent test results.

7)

26.UG.6.4.6 Report**26.UG.6.4.6.1 Material Identification****26.UG.6.4.6.2 Test Results****26.UG.6.4.7 Requirements****26.UG.6.4.7.1 Extinguishing Time****26.UG.6.4.7.2 Drip Extinguishing Time****26.UG.6.4.7.3 Burn Length****26.UG.6.4.7.4 Wire Breakage**

APPENDIX A - MEMBERSHIP

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